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**Study of Environmental Impact and  
Environmental Damage from City  
Traffic - Noise and Exhaust Gases**

**Environmental Protection Agency, Research Triangle Park, N C**

**1973**

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STUDY OF ENVIRONMENTAL IMPACT AND ENVIRONMENTAL DAMAGE FROM  
CITY TRAFFIC

- NOISE AND EXHAUST GASES -

Partial Study II 1.1 Analysis of the relations between  
growth in traffic, composition of traffic,  
and extent of exhaust gas loading

II 1.2 Study of the costs of changes to the  
vehicle for reduction of exhaust gas  
emissions.

Assessor: Technological Monitoring Society of the Rhineland  
Cologne

Department of Applied Thermodynamics and Energy Technology

Under contract to  
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Inquiry: STUDY OF ENVIRONMENTAL IMPACT AND ENVIRONMENTAL DAMAGE  
FROM CITY TRAFFIC - NOISE AND EXHAUST GASES

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## 1. INTRODUCTION

The first objective of partial study II 1.1 was to determine the emission load from vehicular exhaust gases. This partial objective was based primarily on the surveys of the Cologne emission register performed under contract to the Minister of Labor, Health and Social Welfare of the State of North Rhine - Westfalia. As a second objective, immission measurements were performed in selected streets of the city of Cologne, and the emission load of these streets was determined at the same time. By using a computer analysis, the relation between vehicular emissions and the resulting immissions was determined, taking the various wind conditions into consideration. The selected streets were then arranged in the city model building blocks as determined by Gluck in partial study I 1.1 in order to make possible a transfer of the relation between vehicular emissions and immissions to other large cities.

In addition, we also determined the frequency with which the measured immission values exceeded the medical immission limits determined in partial study II 2.

In partial study II 1.2, the costs of reducing the emissions of vehicles were determined by means of an inquiry in the automobile industry.

## 2. DETERMINATION OF THE EMISSIONS FROM VEHICLE TRAFFIC

### 2.1 Systematics for Determining Vehicle Emissions

The emissions from a vehicle and the proportions of the individual exhaust gas components in the total emission are affected by many factors. These can be classed in two groups,



the traffic-specific and the vehicle-specific characteristics. The traffic-specific characteristics are described by the traffic density, i. e., by the number and driving behavior (driving modes) of the vehicles moving on the section under consideration. The vehicle-specific characteristics include the design features such as the type of engine operation (Otto or Diesel operation), the preparation of the mixture (by a carburetor or by injection for an Otto engine), by the displacement, compression ratio, etc., and, among other things, by the age and state of maintenance of the vehicle [1].

Figure 1 shows schematically the process for determining vehicular emissions as a function of the characteristics previously explained as the starting basis, and the necessary computer operations to arrive at the time and location-related emission of exhaust gas component  $k$ .

From the measurements and counts made in the traffic, one obtains the number of vehicles,  $n(q,t)$  at the emission source  $q$  at time  $t$  as well as the driving mode,  $m$ , for the individual vehicles within the source  $q$  at time  $t$ . From studies on test vehicles with different characteristics, one obtains the emission of the exhaust gas component  $k$  as a function of the driving mode  $m$ .

The proportion,  $a_i$ , of vehicles with the emission characteristics,  $i$ , appears from statistical data on the distribution according to motor type, displacement, power, and age pattern of the vehicles.

As an intermediate step, the average emission,  $e_k(m)$  of the exhaust gas component,  $k$ , is determined for a vehicle



in mode  $m$ . With these quantities and the traffic density, we obtain as the result the amount of exhaust gas component  $k$  emitted at time  $t$  at the source  $q$ .

### 2.1.1 Traffic-specific characteristics

The first step in determining the traffic-specific characteristics is determination of the traffic density on the road section under consideration as a function of the time. This was done principally with traffic counts (cross section counts).

The traffic density, is then calculated from the number of vehicles (separately for cars and trucks) passing a point per hour, their mean speed measured by using a test vehicle, and the length of the route covered.

The traffic density,  $n(q,t)$  is determined as

$$n(q, t) = \frac{a(t) \cdot l_q}{v_m(t)} \quad (1)$$

with  $a(t)$  = traffic in vehicles/hour at time  $t$

$l_q$  = length of the route

$v_m(t)$  = average vehicle speed on the route at time  $t$

The average vehicle speed depends on several other factors than the amount of traffic, such as the traffic control and regulation (lights, signs and speed limits).

The different engine powers of various models of vehicles have only a limited effect on the large city traffic rhythm, because the different powers can have only a minor effect on driving because of the usually high traffic density.

The relatively easily determined average driving speed,  $v_m$ , was used to characterize the traffic status. This simplified description of the traffic status by the average speed assumes a statistically demonstrable relation between the average driving speed and the other parameters characterizing traffic behavior (proportion of standing time, acceleration and deceleration time, and the proportion of constant driving speed). This demonstration was provided with a test vehicle which covered various traffic situations over a long period, so that the proportions of the various operating conditions were determined from the average speed and the average of acceleration and deceleration.

Test cycles were established to determine vehicle emissions. They simulated the actual driving conditions in large city traffic on a vehicle power test stand. These test cycles (driving modes) consisted of successive phases of standing, acceleration, constant speed, deceleration, standing. They meet the following conditions:

1. The time proportions of the individual phases should be identical with the values accepted for street traffic.
2. The average speed of the test cycle should correspond with the average speed of the driving condition to be simulated.
3. The acceleration and deceleration values should be  $1 \text{ m/s}^2$  for passenger cars and  $0.55 \text{ m/s}^2$  for trucks.

Nine driving modes were assigned in the range of 0-100 km/hr as average speeds, characterizing automobile traffic in approximately the following traffic situations:

| Mode | Speed Range<br>(km/hr) | Traffic Situation               |
|------|------------------------|---------------------------------|
| 1    | >65                    | Traffic flowing on expressways  |
| 2    | 55 - 65                | Traffic on arterial streets     |
| 3    | 30 - 55                | Flowing through traffic         |
| 4    | 22 - 30                | Flowing city traffic            |
| 0    | 17 - 22                | Comparison cycle to Europa test |
| 5    | 10 - 17                | Congested city traffic          |
| 6    | 2 - 10                 | Clogged streets                 |
| 7    | 0 - 2                  | Traffic jams                    |
| 8    | 0                      | Cold start, warmup of engines   |

#### 2.1.2 Vehicle-specific characteristics

In order to determine vehicle emissions it is first necessary to determine the average emissions of the exhaust gas components of interest per vehicle for the various driving modes. These were determined experimentally through emission measurements on a driving performance test stand. For this purpose, a number of selected vehicles were run through the established test cycles. The test vehicles were chosen in such a way that the emission values obtained on the test stand could be considered as representative for the total vehicular traffic. The licensing statistics of the Federal Motor Vehicle Office were used as the basis for selection, taking the following selection criteria into consideration: vehicle type (passenger cars and trucks), engine operation (Otto and Diesel engine), displacement, power, and age of the vehicle.

The tests on the test stand were performed with all the vehicles selected (44 passenger cars and some trucks) for the test cycles of all the driving modes. As the final result,

they yielded the average emission of a certain exhaust gas component per vehicle and per unit time as a function of the driving modes and, thus, also as a function of the average speed.

Specifically, the exhaust gas components carbon monoxide, CO, nitric oxide, NO, unburned hydrocarbons,  $C_nH_m$  (based on n-hexane) and carbon dioxide,  $CO_2$ , were measured. Soot was also measured for trucks.

Infrared analyzers were used to measure CO, NO,  $C_nH_m$ , and  $CO_2$ , in agreement with the provisions of Appendix XIV, §47, StVZO. A continuously operating instrument was available for measuring smoke density; it was used for soot determination. Aside from these exhaust gas components, the total exhaust gas volume and the fuel consumption were measured. In addition, emissions of the exhaust gas components lead, Pb (for Otto engines) and sulfur dioxide (as  $SO_2$ ) were calculated from the fuel consumption, using literature values (including statistics from the petroleum industry [2, 3, 4, 5]).

The emission factors for passenger car and truck traffic, determined from test stand data, are presented in Tables 1 and 2. Using these emission factors, it is possible to calculate the vehicle emissions in the streets as a product of the traffic density and the emission factor corresponding to the current mode.

#### 2.1.3 Other surveys done within the emission register

The emissions from the major streets, defined as line sources, can be calculated with the relations indicated so far. Furthermore, we determined, in the framework of the emission register, the emissions from trucks in the inner city streets and the residential and business streets outside the immediate city center. Area sources were defined to cover this part of



Table 1. SPECIFIC CHARACTERISTICS AND EMISSION VALUES FOR PASSENGER CARS

| Driving Mode                                            | 1      | 2      | 3     | 4     | 0     | 5     | 6     | 7     | 8     |
|---------------------------------------------------------|--------|--------|-------|-------|-------|-------|-------|-------|-------|
| Average speed<br>km/hr                                  | 100,0  | 60,0   | 42,5  | 26,0  | 19,5  | 13,5  | 6,0   | 1,0   | 0     |
| Exhaust gas<br>volume<br>std m <sup>3</sup> /vehicle hr | 51,18  | 30,30  | 25,26 | 20,85 | 18,50 | 13,51 | 11,50 | 7,80  | 8,77  |
| Fuel consumption<br>liters/vehicle hr                   | 7,554  | 4,417  | 3,718 | 2,855 | 2,792 | 2,127 | 1,732 | 1,167 | 1,521 |
| Carbon monoxide<br>g/l                                  | 213,5  | 239,5  | 229,3 | 279,9 | 281,1 | 340,0 | 368,7 | 411,6 | 388,4 |
| g/vehicle hour                                          | 1571,4 | 1035,7 | 822,3 | 751,8 | 793,5 | 725,1 | 585,7 | 489,3 | 613,8 |
| g/vehicle km                                            | 15,7   | 17,3   | 19,3  | 28,9  | 40,7  | 53,7  | 97,6  | 489,3 | -     |
| Sulfur dioxide<br>g/l                                   | 0,4    | 0,4    | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   |
| g/vehicle hr                                            | 2,8    | 1,6    | 1,4   | 1,1   | 1,0   | 0,8   | 0,6   | 0,4   | 0,6   |
| g/vehicle km                                            | 0,03   | 0,03   | 0,03  | 0,04  | 0,05  | 0,06  | 0,10  | 0,4   | -     |
| Nitric oxide<br>g/l                                     | 14,5   | 13,5   | 11,2  | 8,7   | 7,7   | 5,9   | 3,5   | 2,0   | 3,2   |
| g/vehicle hr                                            | 107,6  | 61,3   | 42,3  | 25,2  | 22,1  | 12,6  | 6,0   | 2,3   | 3,9   |
| g/vehicle km                                            | 1,08   | 1,02   | 1,00  | 0,97  | 1,13  | 0,93  | 1,00  | 2,30  | -     |
| Hydrocarbons<br>g/l                                     | 7,5    | 7,3    | 8,6   | 10,2  | 10,8  | 12,0  | 12,4  | 12,8  | 13,7  |
| g/vehicle hr                                            | 55,8   | 32,1   | 32,1  | 29,4  | 30,9  | 23,0  | 20,3  | 16,7  | 21,1  |
| g/vehicle km                                            | 0,56   | 0,54   | 0,76  | 1,13  | 1,58  | 1,70  | 3,38  | 16,7  | -     |
| Lead<br>g/l                                             | 0,4    | 0,4    | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   | 0,4   |
| g/vehicle hr                                            | 2,8    | 1,7    | 1,4   | 1,1   | 1,0   | 0,8   | 0,7   | 0,4   | 0,57  |
| g/vehicle km                                            | 0,03   | 0,03   | 0,03  | 0,04  | 0,05  | 0,06  | 0,12  | 0,4   | -     |



Table 2. SPECIFIC CHARACTERISTICS AND EMISSION VALUES FOR TRUCKS

| Driving Mode                                            | 1    | 2    | 3    | 4    | 0    | 5    | 6    |
|---------------------------------------------------------|------|------|------|------|------|------|------|
| Average speed<br>km/hr                                  | 85,0 | 60,0 | 42,5 | 26,0 | 19,5 | 13,5 | 6    |
| Exhaust gas<br>volume<br>std m <sup>3</sup> /vehicle hr | 218  | 169  | 136  | 104  | 92   | 80   | 66   |
| Fuel consumption<br>l/vehicle hour                      | 19,8 | 14,0 | 9,9  | 6,3  | 4,9  | 3,4  | 1,7  |
| Carbon monoxide<br>g/l                                  | 25,3 | 27,3 | 29,7 | 33,3 | 36,3 | 44,7 | 71,8 |
| g/vehicle hr                                            | 501  | 378  | 294  | 210  | 178  | 152  | 122  |
| g/vehicle km                                            | 5,9  | 6,3  | 6,9  | 8,1  | 9,1  | 11,3 | 20,3 |
| Sulfur dioxide<br>g/l                                   | 4,1  | 4,1  | 4,1  | 4,1  | 4,1  | 4,1  | 4,1  |
| g/vehicle hr                                            | 81,2 | 57,4 | 40,6 | 25,8 | 20,1 | 13,9 | 7,0  |
| g/vehicle km                                            | 0,96 | 0,96 | 0,96 | 1,00 | 1,00 | 1,00 | 1,2  |
| Nitric oxide<br>g/l                                     | 6,1  | 6,3  | 7,1  | 8,3  | 9,0  | 9,7  | 12,9 |
| g/vehicle hr                                            | 120  | 88   | 70   | 52   | 44   | 33   | 22   |
| g/vehicle km                                            | 1,4  | 1,5  | 1,6  | 2,0  | 2,3  | 2,4  | 3,7  |
| Hydrocarbons<br>g/l                                     | 1,6  | 1,7  | 1,8  | 2,0  | 2,2  | 2,6  | 4,2  |
| g/vehicle hr                                            | 32,6 | 24,2 | 17,9 | 12,6 | 10,7 | 8,8  | 7,1  |
| g/vehicle km                                            | 0,4  | 0,4  | 0,4  | 0,5  | 0,5  | 0,7  | 1,2  |
| Soot<br>g/l                                             | 2,5  | 1,9  | 1,6  | 1,5  | 1,5  | 1,6  | 2,4  |
| g/vehicle hr                                            | 50,1 | 27,0 | 16,3 | 9,4  | 7,4  | 5,6  | 4,0  |
| g/vehicle km                                            | 0,6  | 0,5  | 0,4  | 0,4  | 0,4  | 0,4  | 0,7  |

the traffic. The traffic density of the area sources in the outer districts was determined by means of aerial photographs. These aerial photographs were taken with an over-coverage of 60%, so that it was possible to distinguish directly between parked and moving vehicles, and so that the speed of the traffic flow could be determined. From these aerial photographs, area-related vehicle densities were determined separately for car and truck traffic. Any line sources passing through the area unit were excluded. The daily course of traffic density of these area sources was determined like the daily course of traffic on the line sources adjacent to these area sources.

The traffic density in the area sources of the inner city region was determined by computation of some representative cross-sectional samples in the inner city. The driving mode was set at 0 over the whole course of the day in the inner city area sources. It was set uniformly at 4 in the other area sources because, due to the relatively narrow streets and numerous crossings, the average speed can generally not exceed the range of mode 4.

The emission from automobile traffic in an area source is computed as:

$$E_k(q, t) = d_f(t) \cdot F_{red}(q) \cdot e_k(m) \quad (2)$$

where  $d_f(t)$  = area-related traffic density at time  $t$   
 $F_{red}(q)$  = total area of the area source, reduced by the proportion which is not built up  
 $e_k(m)$  = emission factor for exhaust gas component  $k$  in mode  $m$ .

## 2.2 Results From the Emission Register

Using the relations presented in Section 2.1, the traffic density and the total emission of the individual pollutants were determined for each line and area source. Figures 2 to 9 present the major results from the Cologne emission register.

Figure 2 shows the distribution of the relative traffic density, determined over one year, for the entire region studied (city region of Cologne and the Dormagen-Worringen-Monheim-Hitdorf area) with respect to car and truck traffic and the various driving modes, as a function of the time of day. Because the traffic density in the area sources makes up a large portion of the total traffic density, driving mode 4 makes up the greatest part in Figure 2, at some 60%, followed by driving mode 3 with some 28%. The driving modes with the relatively low average speeds (5 and 6) occur principally in the periods of evening peak traffic. The relative traffic density shows two distinct peaks, from 7:00 to 8:00 in the morning, and a considerably higher one in the evening hours from 15:00 to 18:00. We can also see from this figure that some 90% of the total traffic occurs in the period of 6:00 - 20:00, and that it is made up of 93% cars and only 7% trucks.

The average specific traffic density on the line and area sources of the region studied is shown in Figure 3. By the average specific traffic density we mean the annual traffic density referred to one hour and to the length or area unit of the line or area source. It has the unit of vehicles/km for line sources and vehicles/km<sup>2</sup> for area sources, so that it also corresponds with the yearly average number of vehicles moving in a source unit.

As can be seen from Figure 3, the highest traffic density occurs on line sources in the inner city of Cologne. The decrease in traffic density on arterial streets and the ring streets of the city region left of the Rhine generally corresponds to the distance from the center of the city. The traffic density in the area sources depends essentially on the density of building in the corresponding source. Thus, high traffic densities occur not only in the inner city but also in densely built up regions at the edge of the city and in areas with strong concentrations of industry.

Figures 4 to 9 show the annual specific exhaust gas emissions for the components carbon monoxide, unburned hydrocarbons, nitric oxide, lead, soot and sulfur dioxide on emission density maps. The annual specific exhaust gas emissions correspond to the annual emissions referred to the unit length of line sources or to the unit area of area sources. They have the units tons/yr km for line sources and tons/yr km<sup>2</sup> for area sources.

There is normally not a direct proportionality between traffic density and emission loading, as the emission loading is calculated from the traffic density and the emission factors, which depend on the driving modes. Furthermore, as a rule, one cannot make direct conclusions from knowledge of the emission loading of one exhaust gas component for various sources about a second exhaust gas component, because there is no linear relation between the emission factors of these two exhaust gas components as a function of the average speed.

As Figures 4 to 7 show, however, there is a certain proportionality between the traffic density and the emission loadings for the components CO, C<sub>n</sub>H<sub>m</sub>, NO and Pb for most sources. The sources with the highest traffic densities always show the highest emission loadings. As Figure 2 shows, driving



modes 3 and 4 overwhelmingly characterize the driving conditions in the region studied, so that to a good approximation we may state an average emission load for a large city region using the emission factors for these modes, which are within a narrow range. But if we consider the emission loads from the exhaust gas components soot and  $\text{SO}_2$  (Figures 8 and 9) we can detect no proportionality to the traffic density. The emissions from these two exhaust gas components are principally ( $\text{SO}_2$ ) or exclusively (soot) caused by truck traffic. The proportion of truck traffic in the total traffic in the individual city areas differs greatly and is essentially determined by the industrial concentrations.

From Figures 7 and 8, in which the emission densities of the components lead and soot are presented, we can draw direct conclusions on the distribution of car or truck traffic densities, because the lead emissions can be ascribed solely to the passenger car traffic, and the soot emissions solely to truck traffic. For lead as an exhaust gas component, there is still a certain proportionality between the emission load and the traffic density because of the high proportion (about 93%) of passenger car traffic in the total traffic. But if we consider the soot emissions, we can see from the emission density distribution that the city core proper, which has the highest traffic density, is relatively little loaded. The highest soot emission densities occur instead in the industrial and commercial regions of the city of Cologne.

The distribution of the  $\text{SO}_2$  emission density can be seen in Figure 9. Due to the high involvement of trucks in the  $\text{SO}_2$  emission, the distribution of this exhaust gas component essentially corresponds to the distribution of the soot emission density.



### 3. IMMISSION MEASUREMENTS IN THE COLOGNE CITY AREA

#### 3.1 Performance of the Immission Measurements

Now we shall attempt to establish a comparison between the exhaust gas emissions from vehicle traffic and the resultant immissions, using suitable immission measurements. The immission measurements were done at 14 selected streets in the city of Cologne. The average measuring time was 2 - 3 days per site. The traffic and the driving behavior of the traffic flow passing was determined simultaneously at these sites. Using the emission factors in the emission register and computer programs, the emission load from vehicle traffic was calculated in the streets under consideration.

The immission loading of the exhaust gas component, carbon monoxide (CO), was determined at all 14 measuring sites. In the later measurements it was also possible to measure the components: unburned hydrocarbon ( $C_nH_m$ ), nitrogen oxides ( $NO_x$ ) and sulfur dioxide ( $SO_2$ ). Only summary measurements could be obtained for the unburned hydrocarbons. Only at one measuring site was it possible to distinguish between the sum of the nitrogen oxides ( $NO_x$ ) and nitrogen dioxide ( $NO_2$ ).

As the immission values, aside from the traffic-specific and city design parameters, are very strongly affected by meteorological parameters, and especially by the wind conditions, these meteorological quantities were determined synchronously with the immission values. Specifically, the following quantities were determined: air temperature, air pressure, relative humidity, and the wind direction and speed in the street cross section investigated (local wind conditions). In order to be able to transfer the results obtained in comparison of vehicle emissions and immissions using some selected

measuring sites to the whole city and, as much as possible, to other large cities, it was necessary to assign the measured immission values to the large-scale (global) wind conditions.

### 3.2 Description of the Measuring System

The measuring equipment for continuous determination of exhaust gas components was installed in a measuring truck.

#### 3.2.1 Design of the measuring truck

The design of the measuring truck can be seen from Figures 10 to 12. The prefilters for the gas analyzers and the air sampling points were placed on two rods at different heights. The first measuring rod was always set up at the height of the edge of the sidewalk. It carried the sampling points for continuous measurement of  $C_nH_m$ ,  $NO_x$  and  $SO_2$ , as well as a sampling point for intermittent CO measurement (see Section 3.2.2) at a height of 0.75 m. Another sampling point for intermittent CO measurement was placed at 1.5 m height.

The second measuring rod was always directly at the building line for the street being investigated. On the second measuring rod the heights of the sampling points for intermittent CO measurement were 0.75 m, 1.5 m and 4.5 m. The horizontal distance between the two measuring rods was that of the sidewalk width. With this arrangement of sampling sites it was possible to determine the spreading behavior of vehicle exhaust gas in the region of the pedestrian zone along the streets.

### 3.2.2 CO measurement

The component, carbon monoxide, was measured with a Uras 2 (Infrared Absorption Recorder). The functioning of the instrument is described in Figure 13. Figure 14 shows the switching plan used for this measurement. The gas to be measured was drawn in continuously with a diaphragm pump and introduced to the Uras instrument through equal distances. The valve control and interrogation of the gas measuring points occurred synchronously with the switching of the individual measuring points in the six-color point printer.

The measuring range for the Uras 2 is 0 - 200 ppm CO. The maximum accuracy is  $\pm 4$  ppm.

### 3.2.3 $C_nH_m$ measurement

A flame ionization detector (FID) was used for continuous measurement of hydrocarbons. Figure 15 shows the piping diagram for the instrument. The air to be studied is drawn in through a suction line by a pump and led to the flame ionization detector. A sensitive throttle valve regulates the pressure of the gas being measured. It is fixed and checked with a sensitive pressure measuring instrument. In the FID, the air is mixed with hydrogen and introduced into the combustion chamber. The air needed for combustion is introduced into the combustion chamber through a second jet. Ions are produced in the combustion chamber. The ion current is a measure of the hydrocarbon content of the air. An auxiliary current controlled with a potentiometer shifts the zero point to suppress the ion current derived from the hydrogen flame alone.

Only the total hydrocarbons could be measured with this instrument. Classification into individual components is not

possible. The time delay of the measurement indication is extremely low, some 8 milliseconds.

The measuring range of the FID is 0 - 100 ppm. The accuracy is  $\pm 2$  ppm.

#### 3.2.4 NO<sub>x</sub> and NO<sub>2</sub> measurement

The NO<sub>x</sub> and NO<sub>2</sub> detectors work electrolytically. A constant steady flow of the gas to be measured and a constant steady film of reaction solution react. The composition of the reaction solution changes, corresponding to the concentration of the components measured. The measurement and reference points are half-elements separated by a diaphragm. Due to the altered concentration of the reaction solution after reaction of the measured component with it, a current proportional to the concentration of the measured component flows through a resistance which is low in comparison to the internal resistance of the cell. The voltage drop appearing at a variable resistance is taken through a constant, adjustable counter voltage to an amplifier. There is a load resistance at the output of this amplifier, where the amplified measurement voltage can be sampled and recorded with a recorder.

The measuring range of the NO<sub>x</sub> and NO<sub>2</sub> analyzers used is 0 - 500 ppb.

#### 3.2.5 SO<sub>2</sub> measurement

The SO<sub>2</sub> concentration was measured in the range of 0 - 1.5 mg/m<sup>3</sup> with a Wösthoff instrument (Ultragas 3), which works by a chemical-physical method. The gas to be studied is brought into contact with a specific absorption liquid. The resulting change in the electrical conductivity of this



liquid is a direct measure of the gas component to be measured.

### 3.2.6 Measurement of meteorological quantities and traffic

The wind speed and direction of the local wind (in the immediate vicinity of the measuring point) were measured with an electrical remote wind measuring instrument. The measuring ranges of this system were 0 - 30 m/s for speed and 0 - 360° for wind direction.

Air temperature, air pressure and relative humidity were recorded with a meteorograph. The meteorograph and the remote wind measuring system were mounted on the roof of the measuring truck.

A sliding contact and pulse counter which printed number of vehicles at 10 minute intervals served to record the time course of traffic. The proportion of trucks was determined in the same traffic by manual counting, so that the car and truck portions could be determined separately.

### 3.3 Selection of Measuring Sites

The measuring sites were chosen by means of surveys of the emission register, with consideration of the city model blocks according to Glück [6]. Of the 12 city model blocks defined by Glück, immission measurements were done for five models. Figure 16 shows the geometric dimensions of these models. At present, the remaining city model blocks cannot be found in Cologne, or show so little traffic that an immission measurement at these sites is not defensible within the framework of this research contract.



The position for the measuring truck was, as much as possible, always established at a great distance from a side-street crossing. This was to eliminate the effect of a potential collection of cars on a traffic sample, as well as to eliminate any falsifying wind effects from cross streets.

The measuring sites in Cologne are shown in Table 3 and in Figures 17 and 18.

Table 3. SURVEY OF MEASURING SITES

| Measuring Site | Street Model | Measuring Time (hrs) | Street           |
|----------------|--------------|----------------------|------------------|
| 1              | 2            | 61,5                 | Bonner Str.      |
| 2              | 4            | 30                   | Ulrichgasse      |
| 3              | 4            | 31,5                 | Cäcilienstr.     |
| 4              | 2            | 43                   | Kalker Hauptstr. |
| 5              | 1            | 32                   | Ehrenstr.        |
| 6              | 4            | 71                   | Hohenzollernring |
| 7              | 4            | 30                   | Aachener Str.    |
| 8              | 10           | 23                   | Innere Kanalstr. |
| 9              | 1            | 30                   | Vogelsanger Str. |
| 10             | 2            | 46                   | Antwerpener Str. |
| 11             | 6            | 32                   | Adenauer Ufer    |
| 12             | 1            | 36                   | Richmodstr.      |
| 13             | 1            | 32                   | Friesenstr.      |
| 14             | 4            | 34                   | Hohenzollernring |

Table 3 gives a total measuring time of 532 hours. This was distributed as follows over the individual city model blocks: Model 1: 130 hrs; Model 2: 150.5 hrs; Model 4: 196.5 hrs; Model 6: 32 hrs; Model 10: 23 hrs.

The exhaust gas component, CO, was measured intermittently at these measuring sites (see Section 3.2.2). At measuring sites 4 (partially), 6, 7, 8, 9, 10 and 11, the components  $C_n H_m$ ,  $NO_x$  and  $SO_2$  were also measured continuously at a height of 0.75 m above the sidewalk edge. At measuring site 6 there was also a partial measurement of the component  $NO_2$ .

### 3.4 Presentation of the Immission Measurements

#### 3.4.1 Concentration curves for measuring points at which only the component CO was measured.

Two diagrams were plotted daily for each measuring site where only the component CO was measured. All the measurements of the quantities indicated in the diagrams are half-hour averages. In the first diagram, the lower presentation on the left half of the page shows the daily course determined for traffic, plotted separately for car and truck traffic, and the daily course of the average driving speed and the driving modes in the street section considered.

The diagram above that contains a comparison of the daily course of the measured CO immission concentration of measuring point 5 (0.75 m above the edge of the sidewalk) and the CO emission per kilometer of street length, calculated from the traffic, the driving modes, and the emission factors from Tables 1 and 2.

The daily courses of the CO immission concentration at the various measuring sites are plotted in the third diagram at the left half of the figure.

The top diagram shows the daily course of the local wind speed measured in the immediate vicinity of the immission measuring site (see Section 3.2.1).

The essential features of the daily courses of the meteorologic quantities are presented in the right half of the first diagram. The lower diagram shows the course of the air temperature. The air pressure and relative humidity are plotted also. In order to ensure the assignment of the local "wind direction in relation to the street direction" to the time of day, the street axis is shown displaced by  $90^\circ$  from the actual street direction. The absolute angle of the local wind can be read from the wind rose with the wind frequency for the measuring day. Thus, it is also possible to assign the "wind direction in relation to the street direction" to the building or situation sketch in the upper right part of the figure. This sketch indicates the position of the measuring rods or measuring points, respectively, with two large points.

The second diagram to be assigned to the measuring day shows a comparison of the local and global wind velocities.

#### 3.4.2 Concentration curves for measuring points at which all the waste gas components were measured.

Four diagrams per measuring day were plotted for each measuring site at which all the exhaust gas components were measured. The left half of the first diagram shows, along with the daily course of the traffic, the daily course of the immission concentrations of carbon monoxide (CO), unburned hydrocarbon ( $C_nH_m$ ), nitrogen oxide ( $NO_x$ ) and sulfur dioxide ( $SO_2$ ) for measuring point 5 (0.75 m high at the edge of the sidewalk). The daily course of the meteorologic parameters, air temperature, local wind speed, relative humidity, and air pressure, are presented in the right half of the figure. The direction and frequency of the local wind is also plotted. Here again, the wind direction to the course of the street is displaced by  $90^\circ$  to the actual street axis. The situation sketch for the measuring site is in the upper right part of the figure.

The second diagram for the measuring day contains a comparison of the immissions presented in the first diagram and the calculated emissions for the components CO,  $C_nH_m$  and  $NO_x$ . The daily courses of the average driving speeds and of the traffic, needed to calculate the emissions, were presented in the lower left part of the figure. The right half of the figure contains the daily course of the air temperature and of the local wind velocity, as well as the wind direction with respect to the street, the frequency of the local wind, and the situation sketch for the measuring point.

The daily course of the CO immission for the various measuring points as well as the meteorologic parameters, air temperature, relative humidity, wind speed, wind direction and wind frequency for the local wind are plotted in the third diagram.

The fourth diagram contains the comparison of the local and global wind speeds for the particular measuring day.

#### 3.4.3 CO concentration average

The diagrams described in Sections 3.4.1 and 3.4.2 show the course of the 30-minute immission concentration averages. These values can be compared with the short-term maximum acceptable concentrations (30 minutes) given in the medical partial study III 2. In this study, however, considerably greater weight is placed on stating the 24-hour concentration average, and, therefore, on a comparison with the long-term (24 hour) maximum acceptable concentration.

Table 4 summarizes the 24-hour averages of the CO immission concentrations at the various measuring points for all measuring sites, except sites 12 and 13, for the individual measuring days.



All the averages were calculated for the daily period from 0 - 24 hours. The actual measuring time per day was some 14 -15 hours for most sites. It was predominantly between 5:00 and 20:00 hours. To determine the 24-hour average, the immission concentrations were extrapolated to the remaining night hours in correspondence with the measured concentration curve. If a reasonable extrapolation could not be performed because of large gaps or omissions in the corresponding measurements, no daily average was stated. This necessarily gives a discrepancy between the measuring times indicated in Section 3.3 and in Table 4.

Statement of a daily average was impossible for sites 12 and 13 because at these sites the daily measuring period did not suffice to make a reasonable estimate of the rest of the curve. At site 4, the CO measuring points 1, 2, and 6 failed for a long period on 20 April 1972. The 24-hour average for the traffic is given in the right column of the table for the individual measuring day. This value was extrapolated over the effective measuring period in a way similar to that for the immission values.

It can be seen from Table 4 that very different concentration averages can appear in spite of identical average traffic. For instance, at site 10 the average of  $n'$  on 1 December 1971 was 356 vehicles/hour, and on 21 April 1972 it was 352 vehicles/hr; but the average CO concentration at point 5 fell from 13.2 to 4.8 ppm. This decrease in the concentration can be ascribed principally to the different wind speeds. While on the first day the average speed of the global wind was 2.1 m/s, on 21 April 1972 it rose to some 3.4 m/s. The same effect of the average wind speed on the average immission concentration could also be determined at site 4 for the dates 9 November 1971 and 20 March 1972.



Table 4. 24-HOUR AVERAGES OF THE CO CONCENTRATION AND TRAFFIC

| Measurement site | Date     | Measuring points |         |         |         |         | n' vehicles per hour |
|------------------|----------|------------------|---------|---------|---------|---------|----------------------|
|                  |          | 1 (ppm)          | 2 (ppm) | 4 (ppm) | 5 (ppm) | 6 (ppm) |                      |
| 1                | 28.10.71 | 5,0              | 5,5     | 5,4     | 5,9     | 5,7     | 756                  |
|                  | 29.10.71 | 5,9              | 5,7     | 6,0     | 6,6     | 6,1     | 887                  |
| 2                | 2.11.71  | 5,5              | 5,3     | 5,3     | 6,3     | 5,7     | 685                  |
|                  | 3.11.71  | 5,6              | 4,5     | 5,0     | 6,3     | 5,5     | -                    |
| 3                | 4.11.71  | 10,9             | 11,3    | 10,3    | 11,7    | 11,4    | 804                  |
|                  | 5.11.71  | 6,1              | 5,5     | 5,6     | 6,6     | 6,4     | 912                  |
| 4                | 8.11.71  | 9,3              | 8,2     | 7,8     | 11,2    | 10,8    | -                    |
|                  | 9.11.71  | 5,2              | 5,5     | 5,4     | 6,7     | 5,6     | 1113                 |
|                  | 20. 4.72 | -                | 4,6     | -       | 5,2     | -       | 1123                 |
| 5                | 15.11.71 | 6,6              | 6,2     | 8,0     | 8,9     | 8,0     | 121                  |
|                  | 16.11.71 | 6,5              | 7,1     | 8,0     | 8,0     | 7,2     | 143                  |
| 6                | 3.12.71  | 15,5             | 14,0    | 12,6    | 18,4    | 16,8    | 664                  |
|                  | 15. 6.72 | 7,4              | 8,4     | 6,4     | 8,7     | 8,5     | 494                  |
|                  | 13. 7.72 | 10,3             | 9,3     | 9,3     | 10,5    | 10,8    | 520                  |
|                  | 14. 7.72 | 9,4              | 8,9     | 9,7     | 10,3    | 9,7     | 711                  |
| 7                | 27.12.71 | 7,0              | 6,8     | 6,0     | 7,8     | 7,4     | 1411                 |
|                  | 28.12.71 | 6,2              | 5,7     | 5,6     | 6,2     | 6,2     | 591                  |
| 8                | 22.12.71 | 6,3              | 6,1     | 5,6     | 9,3     | 9,5     | 141                  |
| 9                | 20.12.71 | 7,8              | 6,3     | 5,5     | 10,3    | 8,5     | 377                  |
|                  | 21.12.71 | 10,2             | 9,3     | 6,8     | 11,6    | 8,9     | 410                  |
| 10               | 1.12.71  | 11,0             | 10,8    | 11,4    | 13,2    | 13,2    | 356                  |
|                  | 2.12.71  | 10,8             | 11,3    | 9,6     | 12,4    | 11,7    | 370                  |
|                  | 21. 4.72 | 4,7              | 4,7     | 4,4     | 4,8     | 4,3     | 352                  |
| 11               | 29.12.71 | 4,0              | 4,0     | 3,4     | 6,7     | 5,2     | 1242                 |
|                  | 30.12.71 | 3,8              | 4,1     | 4,0     | 4,5     | 4,3     | 1060                 |
| 14               | 18.11.71 | 6,7              | 6,6     | 7,3     | 8,2     | 7,5     | 290                  |
|                  | 19.11.71 | 7,9              | 7,7     | 8,4     | 8,9     | 9,3     | 594                  |

For point 5 the immission concentration decreased from 6.7 to 5.2 ppm. This was due to a rise in the average wind speed from 3.4 to 4.6 m/s.

The differences in the average traffic, some of which are considerable, can be explained primarily by variations in the course of the week, as for sites 6 and 14. Both of these sites were on a heavily traveled inner city circular street. The maximum traffic was always observed on Friday, so that the maxima of  $n'$  were always on Fridays during the measuring period (on 19 November 1971 and 14 July 1972).

If we compare the 24-hour average of the CO concentration for the individual measuring points with each other, it is striking that the highest daily average appears predominantly at point 5. Exceptions from this are at site 6 (13 July 1972), site 8 (22 December 1971) and site 14 (19 November 1971). These sites were characterized by a great street width. It could also be observed that on the specified days the direction of the global wind was overwhelmingly identical with the street direction. Because of the good ventilation in the street cross section which this caused, the harmful material was distributed more evenly in the street cross section than with a wind perpendicular to the axis of the street. After point 5, the second-highest CO concentration averages were found primarily at point 6, i. e., on the average, the highest immission concentrations appeared at the edge of the sidewalk. The ratio of the average concentration of the three measuring points at the building line to the average concentration at the edge of the sidewalk depends on the width of the sidewalk and on the prevailing wind direction for the day.

### 3.5 Discussion of the Immission Measurements

In order to explain the results obtained in the immission measurements, we shall at this point go into more detail for one measuring day. As an example, we have selected measuring site 6, and the measurement of 3 December 1971. Measuring site 6 was on a heavily traveled inner city circular street which is assigned to street model 4 because of its geometric dimensions. The exhaust gas components CO,  $C_nH_m$ ,  $NO_x$  and  $SO_2$  were measured at this site. The first diagram for this day shows the meteorological quantities, the building sketch, the traffic density, and lines for the daily courses of the immission concentrations of the 4 exhaust gas components at measuring point 5 (0.75 m above the edge of the sidewalk). As comparison of the daily lines for the traffic density and the CO immission concentration shows, both curves run almost parallel. Only in the evening hours (after 17:00) does the immission concentration rise more in proportion to the traffic density. This is primarily due to slackening of the global wind. The local wind speed, measured in the immediate vicinity of the immission measuring site, remains approximately constant over the entire course of the day. Thus, large jumps in the immission concentration curve should be ascribed not so much to the local wind conditions, as to a change in the global wind.

If we ignore small fluctuations in the CO concentration curve, the  $C_nH_m$  concentration runs about parallel with it. The two other harmful components,  $NO_x$  and  $SO_2$ , in part diverge considerably from the CO concentration curve. This is primarily due to the fact that the concentration of both these components is affected considerably more strongly by other groups of emitters (industry and home fires) than are carbon monoxide and unburned hydrocarbons. In the winter months, especially,

we must expect a strong rise in  $\text{SO}_2$  and  $\text{NO}_x$  emissions from the house fire group of emitters.

The second diagram for the measuring day shows principally a comparison of the immission concentrations measured at point 5 and the calculated exhaust gas emission of the components  $\text{CO}$ ,  $\text{C}_n\text{H}_m$  and  $\text{NO}_x$ . Along with the traffic density, the daily course determined for the average speed and the emission factors in Tables 1 and 2 served as the bases for calculating the emissions. In order to avoid the discrepancy between the immission measurements at points and the emission data, which are usually referred to the source length (street length), the emission was stated in  $\text{kg/hr km}$  for these presentations, independently of the source length. As the two quantities, emission and immission, cannot be converted to each other directly, in this presentation we do not so much compare the actual quantities of emission and immission (in  $\text{kg/hr}$  and  $\text{ppm}$ , respectively) as the different course of immission and emission. In this diagram it is particularly striking that the courses of  $\text{CO}$  emission and  $\text{CO}$  immission agree rather accurately in the mid-day hours (about 10:00 - 15:00). At other times this agreement was not as clear. If we analyze the relation more accurately, we can see that at the times in which the driving modes remain constant (this can be seen from the bottom diagram) the relation between  $\text{CO}$  emission and  $\text{CO}$  immission also remains about linear, aside from the effects of some sudden wind fluctuations. This linearity is always interrupted by a change from one driving mode to another.

If we make a comparison between the daily courses of  $\text{CO}$  emission and immission for several measuring days, it becomes clear that the speed ranges chosen for the individual driving modes, which appeared quite usable for the emission



surveys, appear too coarsely stepped in the comparison with the immission measurements. In addition, it is clear that the transitions from one mode to another do not occur abruptly at a certain time, but instead progressive transitions may occur. This will also appear in the mathematical evaluation of the measurements. But progressive transitions could not be considered in the prescribed calculation schema for the emission values.

A comparison of immission and emission of the component  $C_n H_m$  led to about the same results as that for CO. But basic differences appeared for  $NO_x$ . While the  $NO_x$  emission plotted can be related only to automobile traffic, the  $NO_x$  immission concentration includes a considerable portion from the industrial and house fire emitter groups, as already explained. Therefore, correlation of the  $NO_x$  emissions and immissions would not lead to the same results as for CO.

The third diagram for the measuring day shows the daily course lines for the CO immission concentration at the 5 different measuring points. All 5 show about the same course: gentle rise to about 8:00, a relatively small morning peak from 8:00 to 9:00, a constant period from 10:00 - 15:00, a distinct reduction of the concentration in the period 15:00 - 17:00 due to the increase in the global wind velocity, and, finally, a distinct evening peak until about 18:30. Thereafter the CO concentration decreases, approximately corresponding to the reduction in traffic density.

If we compare the heights of the immission concentrations at the separate measuring points, then, aside from the morning peak, we get the following sequence: Measuring point 5 (0.75 m above the edge of the sidewalk) with the highest concentrations,

followed by point 6 (1.5 m above the edge of the sidewalk), and then the points at the building line, in the sequence: 1 (0.75 m height), 2 (1.5 m high) and 4 (4.5 m high). On the average, then, the highest concentrations were measured at the edge of the sidewalk. We can also see that the immission values decrease distinctly at a relatively low height. The difference between points 1 and 4 was some 10 ppm in the afternoon. The difference in concentration values for points at the same height (building line and sidewalk edge) was some 4 - 5 ppm for the height of 0.75 m, and some 5 - 6 ppm for 1.5 m.

In the daily periods with high traffic, this distinct decrease in concentration with increasing height of measurement could no longer be detected at some sites. Apparently the turbulence in the street cross section increases at these times, due to the higher vehicle rate. This very strongly affects the spread of the harmful components.

The fourth diagram for measuring day 3 December 1971 shows the comparison of the local wind velocity determined in the immediate vicinity of the measuring site and the global wind speed measured at the Cologne-Bonn airport. These global wind conditions, however, are only with reservations transferable to the entire city region of Cologne. Because of the different heights of buildings in the individual parts of the city, and because of geodetic unevennesses, the wind conditions in the various districts of the city can in part be very different from each other and from the reported global wind conditions. Furthermore, it should be noted that a shift can occur in the statement of the wind speed for a certain time due to the different distance of the city regions from the Cologne-Bonn airport. The magnitude of this shift depends not only on the distance (averaging about 16 km) but also on the wind direction. It appears that from a comparison of the two wind conditions

(global and local) we cannot establish any definite relations over a long period, but only for some hours. But if one relates the measured immission values to the wind conditions, one can establish that the dependence of the immission concentration on the global wind is considerably more than its dependence on the wind conditions determined in the street cross sections. From this we can conclude that the magnitude and the distribution of the harmful components are determined essentially by the wind conditions above the particular street cross sections (global). This effect was also confirmed by measurements by Georgii in Frankfurt [8]. The relation of the immission value to the global wind also offers the advantage that its regularity in respect to wind direction and velocity distribution is known with sufficient statistical reliability for any large city.

### 3.6 Analytical Evaluation of the Immission Measurements

Earlier measurements by Georgii in the city area of Frankfurt [8] at individual measuring points in street canyons over long periods have shown that:

- a) the experimental relation between CO immission and vehicle density leads to significant positive CO values with vehicle densities approaching zero;
- b) the immissions differ significantly on the upwind and downwind sides, even for a street build up on both sides;
- c) even in a street with high buildings at the edge, the immissions are more strongly correlated with the wind speed above the roof than with the wind speed measured locally in the street.

These findings, which are essentially confirmed by the present measurements, already show that the spreading process is generated by the development of complex flow fields, which

depend on a multitude of parameters. Here, too, one will be able to apply the basic equations of turbulent diffusion, expressed in a system of differential equations. But it cannot be expected that one will arrive at simple solutions. At the present status of basic research, we lack even the knowledge of the exchange parameters to arrive at a pure numerical solution of the equation system. An analysis must, therefore, attempt to filter out supplementary statistical relations from the measurements. This is done primarily by using regression.

As the distribution of the immission also depends on many local effects, the results from one measuring site cannot as a rule be transferred to others.

For the problem given, this made it necessary to make measurements with various street models and under different meteorological conditions, in a very limited total extent. The evaluation shows that the differences are even greater than originally expected. But even though the predictive power is limited because of the complexity of the problem and the limited extent of measurements, the evaluation shows tendencies which can even be expressed quantitatively.

Of the various air pollution components, carbon monoxide is considered the guiding substance for the analytical evaluation. Most of the evaluations are based on measuring point 5 which promises the most unambiguous results because of its spatial nearness to the immission source.

Of the quantities which affect the CO immission, we consider primarily the traffic,  $n'$ , and the wind conditions. Marginally, we also consider the effects of high-traffic immission sources at the adjacent crossings.



The traffic,  $n'$ , is formed from the number of vehicles per hour, in which trucks enter only with a certain fraction,  $a$ , corresponding to the ratio of truck to car emission (approximately,  $a = 0.3$ ).

To be sure, wind conditions have been determined at the measuring site itself. But this local wind proves not to be very useful in the evaluation. Apparently it represents too small a segment of the local wind occurrences in the street canyon. By comparison, one has better experience with the wind conditions of the Cologne-Bonn airport, which are available simultaneously. This agrees with the finding at Frankfurt [8] that the immission in a street is more closely related to the wind above the roofs than to the wind measured in the street. Even though the large-scale wind conditions are used in the following, there is still a question as to how the local wind conditions in the vicinity of the individual measuring sites can be described pertinently, to the extent that they are decisive for the spreading behavior. But recent investigations allow us to conclude that there is at least a certain uniformity of the wind conditions in the Cologne area [7].

Furthermore, the airport wind has the advantage for immission predictions that its relationships are well known from meteorological statistics.

### 3.6.1 CO immissions by wind classes

For the CO immission at measuring point 5 we set

$$I = e^{b_0} \cdot e^{b_1 \cdot n'} \quad (3)$$

Here  $I$  = immission in ppm  
 $n'$  = traffic in vehicles/hour.

For each measuring site we distinguish between three wind situations: upwind, downwind, and wind on the street axis. These are defined as follows:

Upwind:  $22,5^\circ < \varphi_{rel} < 157,5^\circ$

Downwind:  $202,5^\circ < \varphi_{rel} < 337,5^\circ$

Street axis: other

(with  $\varphi_{rel}$  = wind direction relative to the street direction).

The latter class is introduced in order to make a distinct boundary between the properties of upwind and downwind, and so as to be able to identify a disturbing effect from nearby street crossings.

In addition, we form two speed classes:

0 - 3 m/s

> 3 m/s

Table 5 gives a survey of the regression coefficients  $b_0$  and  $b_1$  calculated through regression for Equation (3) for the wind classes of the individual measuring sites. The errors of  $e^{b_0}$  and  $b_1$  as well as the correlation coefficient,  $r$ , are also indicated.

The value  $e^{b_0}$  is a kind of basic load at the measuring site without traffic moving. It is considered to be time-independent. Parameter  $b_1$  designates the extent of dependence between immission and traffic. The range of validity for the formula is limited to the traffic observed at the measuring sites. It is striking that the value  $b_0$  is positive throughout. In many cases it is even significantly greater than zero. Also, the value of  $e^{b_0}$  is relatively high in comparison with the averages of the CO immissions at the individual measuring sites. From estimates in another

Table 5. REGRESSION:  $I = e^{b_0} \cdot e^{b_1 \cdot n'}$  AT MEASURING POINT 5  
ACCORDING TO WIND CLASSES

| Street Model/<br>Measuring Site | Wind Position | Speed m/s | No. of Meas. | $e^{b_0}$ | $b_1 \cdot 10^3$ | Error of  |                  | r     |
|---------------------------------|---------------|-----------|--------------|-----------|------------------|-----------|------------------|-------|
|                                 |               |           |              |           |                  | $e^{b_0}$ | $b_1 \cdot 10^3$ |       |
| I/5                             | Upwind        | 0 - 3     | 6            | 8,2       | 1,8              | 1,3       | 2,0              | 0,40  |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
|                                 | Downwind      | 0 - 3     | 8            | 3,7       | 4,9              | 1,1       | 1,0              | 0,89  |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
|                                 | Street axis   | 0 - 3     | 20           | 4,5       | 6,0              | 1,2       | 1,2              | 0,75  |
|                                 |               | Above 3   | 28           | 6,7       | 2,1              | 1,2       | 0,76             | 0,48  |
| I/9                             | Upwind        | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | 59           | 5,0       | 1,5              | 1,1       | 0,19             | 0,73  |
|                                 | Downwind      | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
|                                 | Street axis   | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
| I/12                            | Upwind        | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | 13           | 2,5       | 2,6              | 1,1       | 0,39             | 0,90  |
|                                 | Downwind      | 0 - 3     | 15           | 2,2       | 3,5              | 1,2       | 0,66             | 0,83  |
|                                 |               | Above 3   | 10           | 5,0       | 1,0              | 1,4       | 0,78             | 0,48  |
|                                 | Street axis   | 0 - 3     | 9            | 2,7       | 2,7              | 1,2       | 0,44             | 0,91  |
|                                 |               | Above 3   | 18           | 3,7       | 1,4              | 1,2       | 0,61             | 0,49  |
| II/1                            | Upwind        | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | 12           | 4,5       | 0,67             | 1,4       | 0,20             | 0,74  |
|                                 | Downwind      | 0 - 3     | 32           | 8,2       | 0,0              | -         | 0,21             | -0,03 |
|                                 |               | Above 3   | 46           | 5,0       | 0,22             | 1,3       | 0,20             | 0,17  |
|                                 | Street axis   | 0 - 3     | 14           | 1,8       | 1,4              | 1,5       | 0,35             | 0,75  |
|                                 |               | Above 3   | 15           | 10,0      | 0,20             | 1,6       | 0,39             | 0,14  |

(continued)

Table 5. (continued)

| Street Model/<br>Measuring Site | Wind Position | Speed m/s | No. of Meas. | Error of |                  | r   |      |       |
|---------------------------------|---------------|-----------|--------------|----------|------------------|-----|------|-------|
|                                 |               |           |              | $e_{b0}$ | $b_1 \cdot 10^3$ |     |      |       |
| II/4                            | Upwind        | 0 - 3     | 7            | 1,6      | 0,70             | 2,5 | 0,47 | 0,56  |
|                                 |               | Above 3   | 17           | 1,8      | 0,62             | 1,7 | 0,34 | 0,43  |
|                                 | Downwind      | 0 - 3     | 9            | 8,2      | 0,36             | 1,9 | 0,33 | 0,38  |
|                                 |               | Above 3   | 26           | 6,7      | 0,34             | 1,2 | 0,13 | 0,46  |
|                                 | Street axis   | 0 - 3     | -            | -        | -                | -   | -    | -     |
|                                 |               | Above 3   | 22           | 13,5     | -0,27            | 1,4 | 0,18 | 0,32  |
| II/10                           | Upwind        | 0 - 3     | -            | -        | -                | -   | -    | -     |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
|                                 | Downwind      | 0 - 3     | 51           | 4,1      | 2,3              | 1,2 | 0,30 | 0,74  |
|                                 |               | Above 3   | 25           | 3,0      | 1,5              | 1,3 | 0,43 | 0,58  |
|                                 | Street axis   | 0 - 3     | 13           | 5,5      | 1,6              | 1,4 | 0,63 | 0,61  |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
| IV/2                            | Upwind        | 0 - 3     | 11           | 5,5      | 0,27             | 1,2 | 0,20 | 0,42  |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
|                                 | Downwind      | 0 - 3     | 15           | 3,3      | 1,1              | 1,2 | 0,20 | 0,84  |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
|                                 | Street axis   | 0 - 3     | 15           | 4,5      | 0,39             | 1,2 | 0,13 | 0,63  |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
| IV/3                            | Upwind        | 0 - 3     | 9            | 7,4      | 0,61             | 1,6 | 0,41 | 0,49  |
|                                 |               | Above 3   | 31           | 9,0      | -0,13            | 1,2 | 0,13 | -0,18 |
|                                 | Downwind      | 0 - 3     | -            | -        | -                | -   | -    | -     |
|                                 |               | Above 3   | -            | -        | -                | -   | -    | -     |
|                                 | Street axis   | 0 - 3     | 10           | 7,4      | 0,83             | 1,4 | 0,25 | 0,77  |
|                                 |               | Above 3   | 9            | 5,0      | 0,80             | 1,2 | 0,12 | 0,93  |



Table 5. (concluded)

| Street Model/<br>Measuring Site | Wind Position | Speed m/s | No. of Meas. | $e^{b_0}$ | $b_1 \cdot 10^3$ | Error of  |                  | r     |
|---------------------------------|---------------|-----------|--------------|-----------|------------------|-----------|------------------|-------|
|                                 |               |           |              |           |                  | $e^{b_0}$ | $b_1 \cdot 10^3$ |       |
| IV/6                            | Upwind        | 0 - 3     | 11           | 2,3       | 2,1              | 1,2       | 0,31             | 0,91  |
|                                 |               | Above 3   | 14           | 3,0       | 1,2              | 1,3       | 0,31             | 0,75  |
|                                 | Downwind      | 0 - 3     | 51           | 5,0       | 1,4              | 1,1       | 0,16             | 0,79  |
|                                 |               | Above 3   | 14           | 11,0      | 0,19             | 1,4       | 0,37             | 0,14  |
|                                 | Street axis   | 0 - 3     | 18           | 4,1       | 1,4              | 1,1       | 0,16             | 0,91  |
|                                 |               | Above 3   | 21           | 10,0      | 0,15             | 1,3       | 0,25             | 0,13  |
| IV/7                            | Upwind        | 0 - 3     | 7            | 1,5       | 0,53             | 1,7       | 0,17             | 0,82  |
|                                 |               | Above 3   | 25           | 5,0       | 0,34             | 1,2       | 0,08             | 0,67  |
|                                 | Downwind      | 0 - 3     | 12           | 6,7       | 0,34             | 1,1       | 0,11             | 0,70  |
|                                 |               | Above 3   | 9            | 6,7       | 0,40             | 1,2       | 0,18             | 0,65  |
|                                 | Street axis   | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
| VI/11                           | Upwind        | 0 - 3     | 12           | 1,7       | 0,73             | 2,1       | 0,38             | 0,52  |
|                                 |               | Above 3   | 7            | 40,5      | -1,3             | -         | -                | -0,17 |
|                                 | Downwind      | 0 - 3     | 8            | 2,5       | 0,88             | 1,5       | 0,27             | 0,80  |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
|                                 | Street axis   | 0 - 3     | 14           | 2,0       | 0,83             | 1,5       | 0,22             | 0,73  |
|                                 |               | Above 3   | 14           | 4,1       | 0,40             | 1,4       | 0,16             | 0,59  |
| X/8                             | Upwind        | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |
|                                 | Downwind      | 0 - 3     | 13           | 5,5       | 0,45             | 1,7       | 0,28             | 0,44  |
|                                 |               | Above 3   | 27           | 2,6       | 0,67             | 1,7       | 0,27             | 0,44  |
|                                 | Street axis   | 0 - 3     | -            | -         | -                | -         | -                | -     |
|                                 |               | Above 3   | -            | -         | -                | -         | -                | -     |

connection [7] it appears that the CO immissions which correspond to the value of  $e^{b_0}$  can scarcely be explained through other sources than automobile traffic.

If one considers the wind effect on the individual measuring sites, one can clearly see a dependence of  $b_1$  and  $r$  on the wind speed. Both parameters decrease almost throughout on transition to higher wind speeds. Apparently the wind acts more strongly on the ground as the speed increases, causing greater ventilation. A series of empty classes naturally makes the comparison difficult.

The potential comparisons are even more limited for estimating the effect of the wind situation. It appears that we can pick out the following regularity:

At low wind speeds the parameters  $b_1$  and  $r$  take on higher values downwind than upwind. This situation reverses at high speeds. This explanation is contradicted essentially by only classes 0 - 3 for measuring site IV/6.

For streets built up on both sides, this means: at low wind speeds, only the upwind side will be included in the wind flow and ventilated, while at higher wind speed, circulation occurs in the street, ventilating the downwind side more strongly. In the case of the street model X, which is characterized by building on one side, an upwind always has an unimpeded effect and provides ventilation even at low wind speeds.

No uniform tendency can be detected for winds in the street axis. To be sure, splitting into two opposing wind classes (in the street direction, and opposite to the street direction) often leads to completely different parameters,  $b_1$ .

As for measuring site II/4, where the negative parameter,  $b_1$ , arises in this manner in Table 5. We cannot say with certainty whether there is actually asymmetric spread here, or whether this is only a random phenomenon. No effect of nearby crossings can be shown in the form of an increased ground-level  $b_0$ .

### 3.6.2 Modification of the trial regression

Table 5 was based on the immission load  $I$  for the measuring point 5. Now it is conceivable that local wind turbulence is the cause for variations at this measuring point, and that the deficiency can still be localized in the other measuring points. Their values could, then, be used to correct  $I$ . In this way, we would get a weighted mean,  $\bar{I}$ , for measuring point 5, representing an average immission load in the region of the measuring site. In fact, improvements in the correlation are obtained in this manner, but they are primarily limited to low wind speeds.

Table 6 shows a comparison of the previous correlation coefficient,  $r$ , and the  $\bar{r}$  based on averaging, for two measuring sites.

Now that the effect of the wind speed can be surveyed qualitatively, we shall again undertake to test whether the wind speed can be included explicitly in Equation (3):

$$I = e^{b_0} \cdot e^{b_1 n'} \cdot e^{b_2 u} \quad (4)$$

The division into wind classes is retained in order to take into account the varying flow conditions depending on the wind direction.

Table 6. CORRELATION  $\bar{r}$  FOR AVERAGED IMMISSION  $\bar{Y}$

| Street Model/<br>Measuring site | Position       | Wind             | r            | $\bar{r}$    |
|---------------------------------|----------------|------------------|--------------|--------------|
|                                 |                | Speed<br>m/s     |              |              |
| I/5                             | Upwind         | 0 - 3            | 0,40         | 0,51         |
|                                 | Downwind       | 0 - 3            | 0,89         | 0,92         |
|                                 | Street<br>axis | 0 - 3<br>Above 3 | 0,75<br>0,48 | 0,73<br>0,67 |
| IV/7                            | Upwind         | 0 - 3<br>Above 3 | 0,82<br>0,67 | 0,83<br>0,63 |
|                                 | Downwind       | 0 - 3<br>Above 3 | 0,70<br>0,65 | 0,93<br>0,61 |

For individual measuring sites, there is a detectable increase in the multiple correlation coefficients,  $r_u$ , as compared to  $r$  (see Table 7). But the improvements do not attain an order of magnitude which would recommend working with Equation (4) in general. The parameter  $b_2$  turns out to be predominantly negative, but sometimes positive, corresponding to the opposing effects of the wind position. For the street axis, however, we find a basically negative  $b_2$ . In these cases there could be ventilation throughout.

We do not consider including other influential quantities in Equation (4) or (3). For instance, the temperature remains relatively constant at the individual measuring sites, so that it would offer no increase in the correlation coefficients. The traffic during the preceding measurement periods (30-minute values) likewise has no detectable effect. Apparently the nearness of the emission source and the measuring point makes it possible for wind movements to remove



Table 7. REGRESSION ACCORDING TO EQUATION (4) FOR TWO MEASURING SITES ( $r_u$  = multiple correlation coefficient)

| Model/<br>Measuring<br>site | Wind<br>Position | $\bar{e}b_0$ | $b_1 \cdot 10^3$ | $b_2$ | $r_u$ | $r$  |
|-----------------------------|------------------|--------------|------------------|-------|-------|------|
| I/5                         | Upwind           | 5,5          | 3,1              | 0,13  | 0,57  | 0,46 |
|                             | Downwind         | 2,7          | 3,6              | 0,54  | 0,93  | 0,89 |
|                             | Street<br>axis   | 7,4          | 2,9              | -0,05 | 0,58  | 0,54 |
| II/10                       | Upwind           | -            | -                | -     | -     | -    |
|                             | Downwind         | 7,4          | 2,2              | -0,3  | 0,78  | 0,64 |
|                             | Street<br>axis   | 6,7          | 1,8              | -0,22 | 0,69  | 0,61 |

the harmful material from the vicinity of the measuring site in the intervening time. Similarly, the mixing altitude and inversion weather conditions, which play a role in the usual diffusion theories, are excluded as factors of influence in this problem [9, 10, 11].

Finally, it should also be mentioned that a linear trial solution of the form  $I = b_0 + b_1 \cdot n'$  in place of Equation (3) does not lead to results of a different nature. Also, changing to hourly averages instead of the present half-hour values does not advance us. Probably we can attain a decisive improvement only with entirely different means: The effect of the environment on the immission level is conjectured to be subject to variations in the course of the day, so that  $b_0$  must be considered time-dependent; i. e.,  $b_0 = b_0(t)$ .

Only a separate series of measurements can serve as a guide for this time course. The existing ones allow no conclusions in this respect.

Furthermore, we may not neglect the difference in immission depending on the driving mode. In principle, to be sure, corresponding emission factors are known; but they have proved to be too coarsely stepped for the evaluation, so that we cannot use them.

### 3.6.3 Generalization to the street model

Generalization of Equation (3) for the street model by means of the parameter values from Table 5 can be done only with considerable reservations. The variations between measuring sites within one street model are too great. The details of the individual measuring sites are also to important, in spite of their being in the same model. Such details include the daily course of the traffic, which can be entirely different for one-way streets and for streets used in going inward or outward.

Also, there are gradual transitions between the street models. In some cases it is hardly possible to make a clear-cut assignment of the measuring site, such as when the geometric dimensions of the street cross section indicate a different model than the traffic does.

Table 8 shows appropriate careful estimates according to equation (3). These deal with averages which, of course, assume that the peculiarities of a street model are reflected in the measured streets in the whole city area. For mixed models of streets, it is desirable to develop a suitable mixing formula.

Because of the numerous gaps in Table 5, no more extensive subdivision by wind conditions is attempted.

Table 8. ESTIMATED EQUATION (3) AT MEASURING POINT 5  
ACCORDING TO THE STREET MODEL

| Street model | Acceptable $n'$ | $e^{b_0}$ | $b_1 \cdot 10^3$ |
|--------------|-----------------|-----------|------------------|
| I            | 200 - 600       | 4,1       | 2,4              |
| II           | 1100 - 1700     | 4,5       | 0,41             |
| IV           | 800 - 1800      | 6,1       | 0,56             |
| VI           | 1200 - 2100     | 2,7       | 0,54             |
| X (1)        | 1200 - 2200     | 3,3       | 0,6              |

(1) Traffic in only one direction.

Apparently Model I is characterized by a high value of the parameter  $b_1$ . To be sure, the scale extends from values of about 1.5 to 4.0. For the other street models, this parameter is rather uniform. The low value of  $e^{b_0}$  for Models VI and X is also worth noting. This appears to mean that a low ground level of immission occurs in streets which are relatively open, in comparison to street canyons built up densely at both sides.

So far, we have discussed only conditions at measuring point 5. The results obtained can be transferred to the other measuring points by means of Table 9. This table shows a summary of the regression coefficients  $b_0$  and  $b_1$  for a linear trial solution, subdivided by street models. The matching correlation coefficients are of the order of 0.8 throughout. They confirm that the mutual dependence becomes less strong as the distance between the measuring points increases, a result which fits expectations.

Table 9. DETERMINATION OF THE IMMISSION,  $I_R$ , AT THE OTHER MEASURING POINTS FROM THE IMMISSION,  $I$ , AT MEASURING POINT 5 ( $I = b_0 + b_1 I_R$ )

| Street Model | Measuring Point 1 |       | Measuring Point 2 |       | Measuring Point 4 |       | Measuring Point 6 |       |
|--------------|-------------------|-------|-------------------|-------|-------------------|-------|-------------------|-------|
|              | $b_0$             | $b_1$ | $b_0$             | $b_1$ | $b_0$             | $b_1$ | $b_0$             | $b_1$ |
| I            | 1,1               | 1,0   | 0,7               | 1,1   | 1,3               | 1,1   | 1,5               | 1,3   |
| II           | 0,7               | 1,1   | 1,1               | 1,0   | 1,3               | 1,1   | -0,7              | 1,1   |
| IV           | 0,95              | 1,1   | 1,4               | 1,0   | 0,60              | 1,2   | -2,0              | 1,2   |
| VI           | 2,4               | 1,0   | 2,7               | 0,9   | 4,0               | 0,8   | -2,2              | 1,5   |
| X            | -1,27             | 1,6   | -2,9              | 1,8   | -2,0              | 1,8   | -6,3              | 1,5   |

#### 3.6.4 Determination of the frequency of excessive values

In the medical partial study II 2, two limiting values were given for the exhaust gas component CO: the long-term maximum immission concentration ( $MIC_L$ ) as a 24-hour average concentration, and the short-term MIC value ( $MIC_S$ ) as a 30-minute average concentration. The limits were determined as  $MIC_L = 10 \text{ mg/m}^3$  and  $MIC_S = 35 \text{ mg/m}^3$ . Assuming an average air temperature of  $20^\circ\text{C}$ , then for conversion of the measured concentration values (ppm) into  $\text{mg/m}^3$  we get the factor  $1 \text{ ppm} \approx 1.17 \text{ mg/m}^3$ . Thus, the limits are  $MIC_L = 8.5 \text{ ppm}$  and  $MIC_S = 30 \text{ ppm}$ .

##### 3.6.4.1 $MIC_L$ value

Table 4 (Section 3.4.2) shows the 24-hour average concentrations determined for CO at the 5 measuring points. This table lists 12 measuring sites with a total of 27 measuring days. On these 27 measuring days, the  $MIC_L$  value of 8.5 ppm



for CO was reached or exceeded:

|                    |            |
|--------------------|------------|
| Measuring point 1: | on 8 days  |
| Measuring point 2: | on 7 days  |
| Measuring point 4: | on 6 days  |
| Measuring point 5: | on 13 days |
| Measuring point 6: | on 11 days |

It appears that when the  $MIC_L$  value is exceeded at measuring point 4, the highest one (4.5 m at the building line), the value is always exceeded at all the other measuring points. It should also be noted that the frequency of exceeding the value decreases both with increasing height of the measuring site and with increasing distance from the edge of the sidewalk.

From the statement of the frequency with which the value is exceeded during the 27 measuring days we cannot draw conclusions about possible excesses above the  $MIC_L$  value over a longer period. The fluctuations in the parameters which affect the immissions are always too great for that with a change from one measuring site to another, even, within the same street model. But for some measuring sites (e. g., site 6) we can establish that the  $MIC_L$  at measuring point 5 is frequently exceeded even with relatively low traffic.

If we divide the 27 measuring days and 12 measuring sites into the known street model, then, with reservations, we obtain the following frequency for exceeding the value at measuring point 5:

|                  |                   |             |
|------------------|-------------------|-------------|
| Street model 1:  | 4 measuring days  | 3 excesses  |
| Street model 2:  | 8 measuring days  | 3 excesses  |
| Street model 4:  | 12 measuring days | 6 excesses  |
| Street model 6:  | 2 measuring days  | no excesses |
| Street model 10: | 1 measuring day   | 1 excess    |

From this comparison we can detect no effect of the street model on the frequency of excesses. For one thing, the measuring period is too short; and for another, only with reservations can we draw conclusions about the totality of a street model from the measuring sites.

#### 3.6.4.2 $MIC_K$ value

Table 10 shows the excesses of the  $MIC_L$  value for CO and the frequency of excesses calculated from them.

Table 10. EXCESSES OF THE  $MIC_K$  VALUE FOR CO, ARRANGED BY MEASURING POINT.

| Measuring Point | Measuring Site | Date     | Excesses | Frequency of Excesses |
|-----------------|----------------|----------|----------|-----------------------|
| 1               | 3              | 4.11.71  | 2        | 0,042                 |
|                 | 6              | 3.12.71  | 3        | 0,063                 |
|                 | 9              | 21.12.71 | 1        | 0,021                 |
|                 | 10             | 1.12.71  | 1        | 0,021                 |
|                 |                | 2.12.71  | 1        | 0,021                 |
| 2               | 3              | 4.11.71  | 3        | 0,063                 |
|                 | 10             | 1.12.71  | 2        | 0,042                 |
|                 |                | 2.12.71  | 2        | 0,042                 |
| 4               | 3              | 4.11.71  | 2        | 0,042                 |
|                 | 10             | 1.12.71  | 2        | 0,042                 |
| 5               | 3              | 4.11.71  | 2        | 0,042                 |
|                 | 6              | 3.12.71  | 10       | 0,21                  |
|                 | 10             | 1.12.71  | 4        | 0,083                 |
|                 |                | 2.12.71  | 2        | 0,042                 |
| 6               | 3              | 4.11.71  | 2        | 0,042                 |
|                 | 4              | 8.11.71  | 1        | 0,021                 |
|                 | 6              | 3.12.71  | 2        | 0,042                 |
|                 | 10             | 1.12.71  | 3        | 0,063                 |

The number of excesses indicates the number of 30-minute concentration values  $\geq 30$  ppm CO for the individual measuring points or measuring sites. The frequency of excesses is always referred to a 24-hour measuring day; i. e., to 48 half-hourly means.

The decrease in CO concentration with height of the measuring site and with the distance from the sidewalk edge is also apparent from this table.

The highest 30-minute average measured for CO was 53 ppm at measuring site 3, a heavily traveled 6-lane inner city street.

#### 4. SUMMARY

The considerations which have been presented have been concerned essentially with the harmful component CO as a guiding component for evaluation of the air pollution caused by automobile traffic. The unburned hydrocarbons could be measured in the immission measurements, with acceptable cost, only as a total concentration, using a flame ionization detector. It was originally planned to refer the medical limits to these total concentrations. It appeared, however, that for an evaluation of the toxicological effect and, therefore, in order to establish a limiting value, it is necessary to know the toxicologically important individual components (such as the aromatics) and their individual concentrations. As it was impossible to separate these single components analytically, we tested whether a reasonable separation might be undertaken using a reliable calculation from the fuel composition. According to Oelert [12] this method of calculation is not valid because, due to the multitude of parameters affecting emission (including

driving status, engine design, operating state of the engine), no closed relation can be stated between the aromatic content of the fuel and the proportions of aromatics, olefins, aldehydes and phenols in the total output of organic substances. Furthermore, because of the differing fuel composition, particularly in respect to the toxicologically relevant materials (aromatics), this calculation cannot be defended. Accordingly, it is impossible to use the total hydrocarbon measurements obtained to evaluate the effect of the immission load or to state limits for this unknown mixture.

The immission load from nitrogen oxides could also be stated essentially only by means of total measurements ( $\text{NO}_x$ ). Only at one measuring site (site 6) could the immission component  $\text{NO}_2$  also be determined. If one compares the daily courses of  $\text{NO}_x$  and  $\text{NO}_2$  at this site, it appears that the relation between these two components does not remain constant, but changes very strongly during the course of the day. But it does not appear reasonable to transfer the results obtained at one site to the others. The recorded immission concentrations of the components  $\text{NO}_x$  and  $\text{NO}_2$  at site 6 do not, however, approach the recommended limits, either for  $\text{NO}_2$  with  $\text{MIC}_L$  (24 hrs) =  $0.1 \text{ mg/m}^3$  (0.05 ppm) and  $\text{MIC}_S$  (30 minutes) =  $0.2 \text{ mg/m}^3$  (0.1 ppm), or for NO (calculated as  $\text{NO} = \text{NO}_x - \text{NO}_2$ ) with  $\text{MIC}_L$  (24 hrs) =  $0.5 \text{ mg/m}^3$  (0.4 ppm) and  $\text{MIC}_S$  (30 min) =  $1.0 \text{ mg/m}^3$  (0.8 ppm). But, as this site showed the highest long-term load and the greatest frequency of exceeding the short-term limit for the guiding component, CO, we can with good probability conclude from that that the immission concentrations of NO and  $\text{NO}_2$  do not exceed these limits at the other measuring sites either.



Mathematical-meteorological diffusion models have been used with great success to estimate the real immissions of harmful materials [10, 11]. Their application to the emissions from automobile traffic in order to calculate the resultant immission load leads to results which can in part deviate from the measured immission concentrations by some orders of magnitude [7]. This comparison shows that the concentrations outside the street canyons reach only a small fraction of the values within the cross section of the street. For this reason, too, it appears that we can neglect the effect of more distant emission sources (streets) on the immission load of individual, typical, highly frequented street canyons in the form of a base level. In the measurements, however, a certain basic load could be detected, and this can be ascribed to the effects of immediately adjacent streets or street crossings and, in part, to other groups of emitters. As this basic load is affected by the fluctuations of the adjacent emitters as well as by the wind conditions, it might also show a definite daily course. The measurement of this basic load assumes that the immission measurement is performed with traffic completely stopped in the street under consideration, and with the surroundings simultaneously undisturbed. But a relatively great expense would be required for that in a large city street system.

The immission measurements were made primarily in the period from October to April. In order to eliminate any possible influence from the house fire group of emitters and to estimate the dependence of the pollutant diffusion on the air temperature and, in particular, the effect of increased solar radiation on the immission load, the measurements were repeated at one site through 4 days in the summer months. In this relatively short measuring period, we could show no effect of the higher temperatures on the immission concentration, at least for CO and  $C_n H_m$ . Only

the concentrations of the components  $\text{NO}_x$  and  $\text{SO}_2$  show slight differences in comparison to the winter measurements. These could be due to a reduction in the pollution produced by house fires.

In the analytical evaluation of the immission measurements we first attempted to correlate the measured immission concentrations with the emissions calculated from the traffic, the mean driving speed, and the emission factors, taking the wind effects into consideration. This attempt led to unsatisfactory results, however. We found correlation coefficients in the range from + 0.6 to - 1.0. That is, the immission values in part show only very weak dependence, or none at all, on the calculated emissions. We could demonstrate distinct dependence between immission and emission only if the driving modes remained constant over a long period. It appeared that the selected speed ranges for characterizing the emission factors for the emission register are too coarsely graded for comparison with the immission values. Thus the progressive transition from one driving mode to another could not be considered with sufficient accuracy. Therefore, in a second trial, the immission measurements were compared directly with the traffic. Trucks were taken into consideration only in the same ratio as that of their emission factors to the corresponding values for passenger cars. This second trial led to a distinct increase in the correlation coefficients. In the calculation, the measured immission values were assigned to the total traffic for the street.

It can also be assumed that the individual traffic lanes will exert a steadily diminishing effect on the emission level determined at the measuring site as their distance from the site increases. Within the framework of this research contract, however, we could not determine this effect, which might lead to another increase in correlation coefficients.

If we compare the results of immission measurements in the cities of Frankfurt and Berlin [8, 13] with the regression and correlation coefficients in Table 5 (Section 3.6.1), it is striking that on the average, these measurements led to higher correlation coefficients. These measurements were done over a relatively long period at only a few sites. Furthermore, the correlation between immission concentration and traffic density was calculated not for the individual measuring day, but for the daily courses of both values averaged over the entire measuring period. This largely eliminated the occasionally considerable variations in the individual daily courses.

But even in the existing studies, the change to average daily values for the measurements done did not give any significant improvement in the correlation. Because of the short measuring time averaging 2 or 3 days per site, only a few measurements could be used in averaging, and some of these were subject to large fluctuations.

In the analytical evaluation, the measured immission values were assigned to the wind conditions determined at the Cologne-Bonn airport. Three classes of wind directions were developed for each site: upwind, downwind, and wind in the direction of the street. We also used two wind speed classes: 0 - 3 m/s and over 3 m/s. In spite of many empty classes, it appeared that the dependence of the immission concentration on the traffic was stronger for downwind than for the other wind directions. In general, a change from high to low wind speeds improved the dependence. But it is still undecided whether referring the immission values to the wind conditions prevailing directly above the particular street cross sections might not have led to more significant results.

The 14 measuring sites were assigned to the city model blocks defined by Glück. There was partial discrepancy between assignment according to the geometrical and traffic-specific viewpoints. The average immission loads listed in Table 8 and shown in Figures 40 to 43 for the five street models covered by measurements are based on conservative estimates. As these values have relatively great uncertainty, we did not attempt a division by wind classes.

So as to be able to state extreme immission loads as a function of the wind situation for individual street models, we must return to the regression coefficients between the immission load and the traffic, listed in Table 5 (pages 33-35) and to the corresponding correlation coefficients. The extreme values can be taken from Figures 19 to 39, which present the measurement results for the different individual measurement sites.

Due to the strong dependence of the immission on the large-scale wind situation, on the local wind effects, and on the different building models, it does not appear reasonable to draw conclusions from the immission results of the Cologne study for streets of similar model structure in other large European cities. The range of variation for the results does not allow any reliable evaluation of the dependence of the immission load on the parameters listed above.

Cologne, 13 February 1973  
Wey/Se/Mz



## Partial Study II 1.2

### STUDY OF THE COSTS OF CHANGES TO VEHICLES WITH OTTO ENGINES FOR REDUCTION OF ENGINE EXHAUST GAS EMISSIONS.

#### 1. INTRODUCTION

Partial Study II 1.1 presented the immissions of harmful material produced by large city street traffic as a function of the vehicle density or of the emissions related to that. In order to make an estimate of the increased cost to the economy from the environmental load and damage caused by automotive emissions, the only tractable way was chosen as that of indirect cost quantification by means of the costs for a single vehicle to reduce the emissions of harmful materials to a prescribed amount. This route was chosen after the research locations contracting to work out this section designated the originally recommended, so-called direct method using the direct estimation of damage and stress as unfeasible.

As the basis for this cost determination, we used the average automobile emission level for 1969. This has also been used as a reference standard in the surveys of the emission register, and, thus, for the emission-immission correlation (see partial study II 1.1) by the Rhineland Technical Monitoring Union.

#### 2. METHOD OF COST DETERMINATION

In order to determine the costs to be expected for reduction of harmful materials, detailed questions were submitted to the individual manufacturers through the Automotive Industry Association (VDA). For this purpose,

the Rhineland Technical Monitoring Union developed a questionnaire which provides a simple and clear disclosure of the increased costs for pollutant reduction.

In this questionnaire, the average emission levels for the pollutants CO, CH and NO<sub>x</sub> were given for the individual vehicle types for 1969 in g/100 g fuel or g/test, corresponding to the provisions of appendices XIII and XIV, respectively, §47, StVZO, for mass production testing. Next, we requested information on increased costs for pollutant reduction, depending on 5 stages of reduction. Appendices XIII and XIV, §47, StVZO, and the test methods and methods for computing to determine the emission values included in them, were the bases for determining costs of the technical measures for the vehicle or engine.

The increased costs for pollutant reduction were to be subdivided into manufacturing costs (DM/vehicle) and operating and maintenance costs (DM/year).

The five reduction stages indicated refer to the pollutants CO, CH and NO<sub>x</sub>. The first planned reduction stage was reduction of the components CO and CH by 20% in comparison with 1969. This reduction generally corresponds to the limits after the Appendices XIII and XIV, §47, StVZO, went into force on 1 October 1971. The other reduction steps correspond to the concepts of the German Federal Government, set down in the Environment Program of 23 December 1971, which plans a long-term reduction of the pollutants CO, CH and NO<sub>x</sub> by 90% as compared to the average emissions of 1969; see also [14]. The individual steps contemplate reduction as follows:

|                    |                                          |
|--------------------|------------------------------------------|
| Reduction stage 2: | CO and CH by 40%, NO <sub>x</sub> by 30% |
| Reduction stage 3: | CO and CH by 60%, NO <sub>x</sub> by 60% |
| Reduction stage 4: | CO and CH by 80%, NO <sub>x</sub> by 80% |
| Reduction stage 5: | CO and CH by 90%, NO <sub>x</sub> by 90% |

Finally, there was to be a statement of the reduction stage at which an exhaust gas purification system would be required for the individual engine types of the manufacturer.

After having presented the plans for cost quantification at a meeting with the VDA and the German automobile manufacturers, and obtaining the basic support of the automobile industry, the Rhineland Technical Monitoring Union distributed the questionnaires through the VDA to the German automobile manufacturers. But in spite of repeated intensive efforts by the VDA, only a few of the manufacturing companies were ready to answer the questionnaire. Up to 31 January 1973, the status of the inquiry was as follows:

Three companies submitted completed questionnaires. One manufacturer sent the questionnaire without data, and another refused. No statements could be obtained from the other manufacturers.

In order to have a statistically reliable economic cost estimate, it would have been necessary to have data from at least two of the three largest German manufacturers. But only one of these was prepared to fill out the questionnaire completely. The other two acceptances were by a middle-sized and a small manufacturer.

### 3. RESULT OF THE INQUIRY

The following data came from one of the largest companies:

Average emission level for the year 1969, corresponding to Appendix XIV, §47, StVZO:

CO: 220 g/test  
CH: 17 g/test  
NO<sub>x</sub>: No data

The increased costs (to the public) were stated as follows:

| Reduction Stage | Increased Costs for            |                        |                      |
|-----------------|--------------------------------|------------------------|----------------------|
|                 | Manufacture<br>DM/vehicle      | Maintenance<br>DM/year | Operation<br>DM/year |
| 1               | 80,--                          | 20,--                  | --                   |
| 2               | 160,--                         | 60,--                  | 100,--               |
| 3               | 600,--                         | 80,--                  | 250,--               |
| 4               | 1.040,--                       | 500,--                 | 450,--               |
| 5               | No effective system known yet. |                        |                      |

The following additional comments were made:

1. Reduction stage 1 has already been verified in the 1972 production with a reduction of 30% for CO and CH.
2. For reduction stage 4, the long-term maintainability of the components and the long-term effectiveness of the system cannot be ensured with known technological means. Fuels are assumed to have specifications linked with significantly higher costs:

Lead ≤ 0.0013 g/l

Phosphorus ≤ 0.0013 g/l

Sulfur ≤ 0.01 % by mass



3. The maintenance costs include a converter change at 20,000 miles of driving.
4. Use of a gas purification system appears necessary beyond the second reduction stage.

It was also stated that the power and "drivability" of the vehicle would decrease from 100% to 95% at reduction stage 1 and to 70% at reduction stage 4.

Data from the second manufacturer (medium-sized company):

Average emission level for 1969, according to Appendix XIV:

|                   |                |
|-------------------|----------------|
| CO                | 250-360 g/test |
| CH:               | 12-16 g/test   |
| NO <sub>x</sub> : | 80-110 g/test  |

| Reduction Stage | Increased Costs for         |                        |                      |
|-----------------|-----------------------------|------------------------|----------------------|
|                 | Manufacturing<br>DM/vehicle | Maintenance<br>DM/year | Operation<br>DM/year |
| 1               | 10,--                       | --                     | --                   |
| 2               | 40,--                       | 10,--                  | 10,--                |
| 3               | 150,--                      | 300,--                 | 110,--               |
| 4               | 370,--                      | 450,--                 | 150,--               |
| 5               | 650,--                      | 600,--                 | 200,--               |

Use of an exhaust purification system required beyond reduction stage 3.

The third manufacturer (small company) reported the following values:

Average emission level of vehicle types for 1969 according to Appendix XIV, §47, StVZO:

CO: 300 g/test  
 CH: 18 g/test  
 NO<sub>x</sub>: no data

| Reduction Stage | Increased Costs for         |                        |                      |
|-----------------|-----------------------------|------------------------|----------------------|
|                 | Manufacturing<br>DM/vehicle | Maintenance<br>DM/year | Operation<br>DM/year |
| 1               | 50,--                       | 50,--                  | --                   |
| 2               | 100,--                      | 50,--                  | 100,--               |
| 3               | 300,--                      | 100,--                 | 200,--               |
| 4               | 1.200,--                    | 300,--                 | 500,--               |
| 5               | 1.400,--                    | 300,--                 | 500,--               |

Use of a gas cleaning system required in reduction stages 4 and 5.

According to a publication by Heitland [15], the consumer must expect the following cost increases on reduction of pollutants: average reduction factor of 25%, about DM 200 to 300; average reduction factor of 80%, DM 700 - 1,100; and average reduction factor of 90%, DM 1,200 to 1,800. These increased costs were not listed according to manufacture, operation, and maintenance costs. They are based on the emission values for the products of model year 1971/1972 in the USA and refer to American market conditions.

#### 4. SUMMARY

As the statements which can be evaluated from the manufacturing companies show, there are some significant differences between the individual manufacturers both in the manufacturing costs and in the operating and maintenance costs. There are in part still no concrete concepts even on the technical accomplishment and the long-term effectiveness of the systems in the area of higher emission reduction, so

that the increased costs reported can serve as reference values at best. The statement of the gas purification time interval varies between reduction stages 2 and 4 for the 3 manufacturers, with a thermal reactor with exhaust gas recirculation being planned for reduction stage 4.

The current cost factors for customer service and repair businesses were used by the individual manufacturers as a basis for stating the increased costs for operation and maintenance.

All three manufacturers emphasized that they made their estimates most conscientiously, but that they had non-negligible errors of unknown magnitude.

It did not appear reasonable to determine a statistically reliable average for the increased costs from the available statements for the economic estimate. Aside from shortcomings and uncertainties previously mentioned, we must also consider that the total number of cars made by the manufacturers which could be evaluated makes up only 25% of all German automobiles.

Thus, we attempted to get useful results in other ways. By way of official aid, we were able to see the study on "Effectiveness and Costs of Measures to Reduce Vehicular Emission of Pollutants (July 1962)", produced by Dornier System under contract to the Federal Minister of the Interior. Eleven automobile manufacturers were asked to cooperate in this study. Six of these were prepared to provide useful data. It appeared, however, that the results of this study are not transferable to the question for this partial study because the inquiry was based on other assumptions.

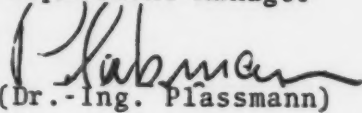
For the reasons presented, it was impossible, in spite of intense efforts, to make representative statements of the average increased cost for a vehicle at the individual reduction stages. Thus, the direct cost quantification from the few numerical statements may have significant uncertainties.

Cologne, 13 February 1973.

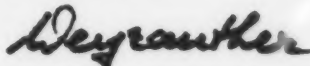
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Department of Applied  
Thermodynamics and Energy  
Technology

Department Manager

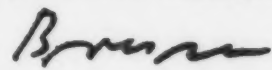
  
(Dr.-Ing. Plassmann)

Specialist

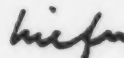
  
(Dipl.-Ing. Weyrauther)

Department of Data Processing  
and Applied Mathematics

Department Manager

  
(Dr. rer. nat. Bresser)

Specialist

  
(Dipl.-Math. Kiefer)



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15. Heitland, H. Possibilities for Exhaust Gas Cleaning for Automobile Engines. Petroleum Technology, Central Petroleum Association, Technical Service, Vol. 16, No. 4, 1971.

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- Figure 22 Dependence of the CO concentration on traffic, street model 1, downwind
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Diagrams of the immission measurements.

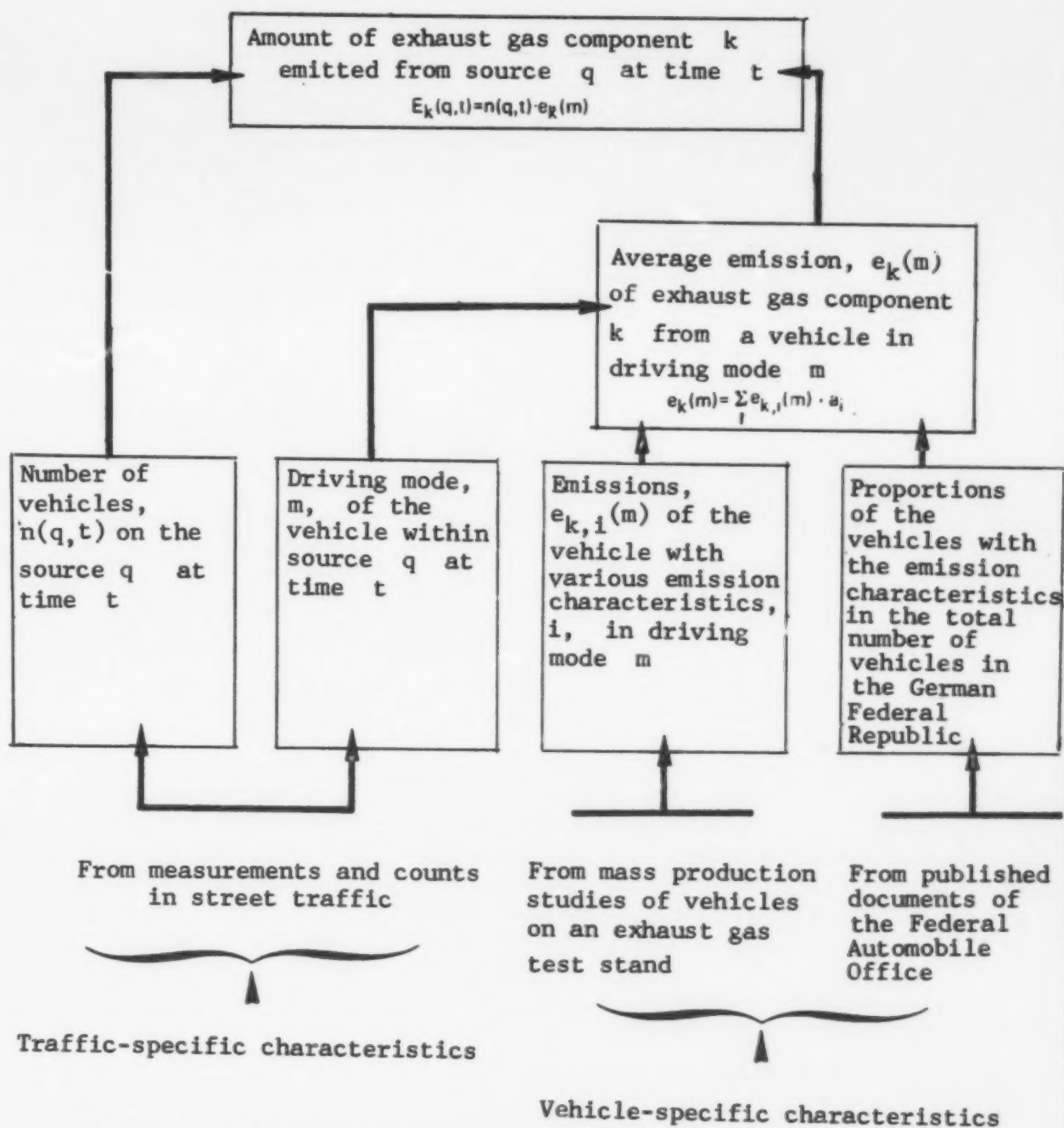
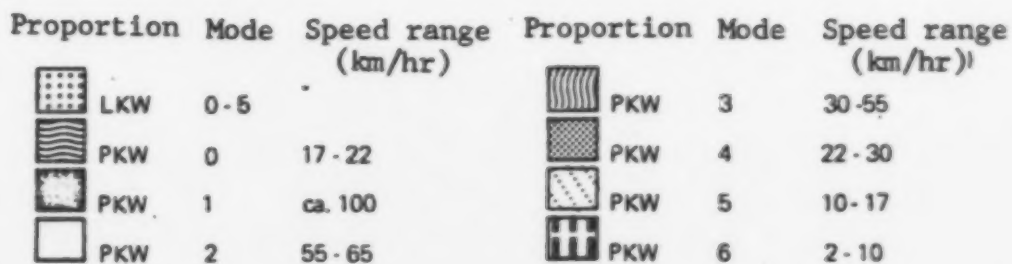


Figure 1 Scheme of the calculation for estimation of exhaust gas emissions from automobile traffic



d = Relative vehicular traffic density  
D<sub>h</sub> = Hourly vehicular traffic density  
D = Daily vehicular traffic density, on a yearly average

65

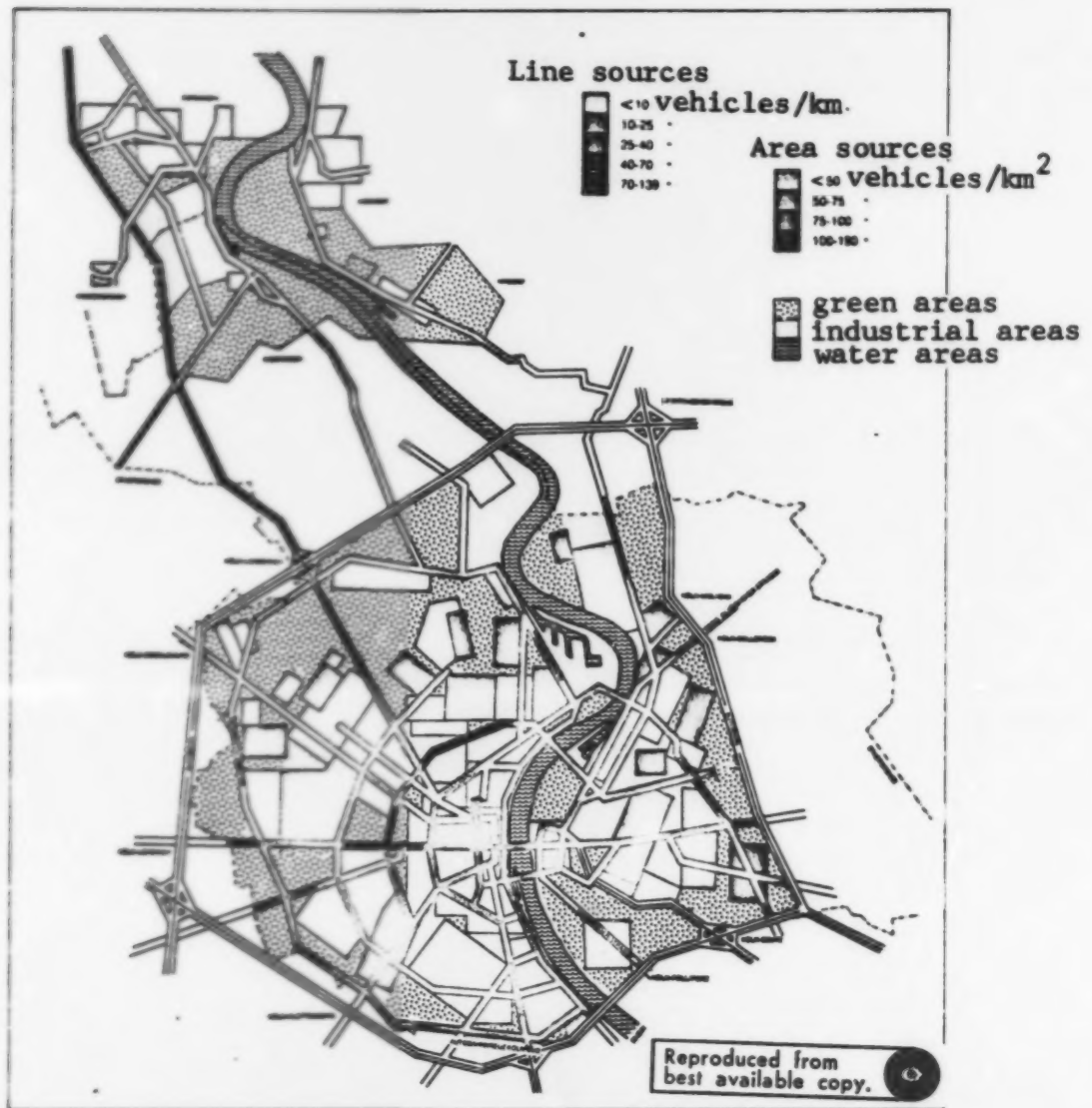


Figure 3 Traffic density for the city of Cologne and vicinity



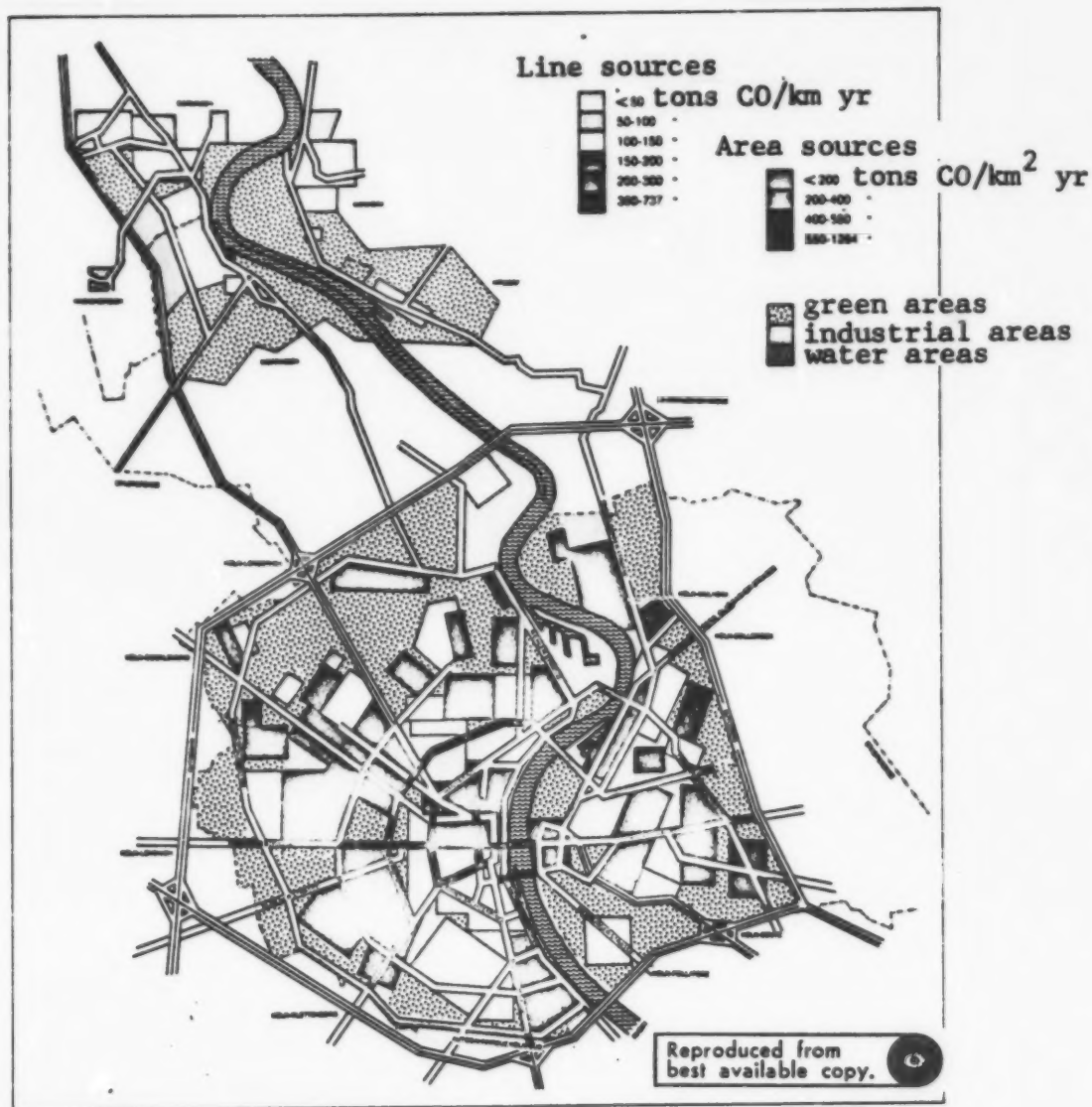


Figure 4 CO emission density for the city of Cologne and vicinity (vehicular traffic)

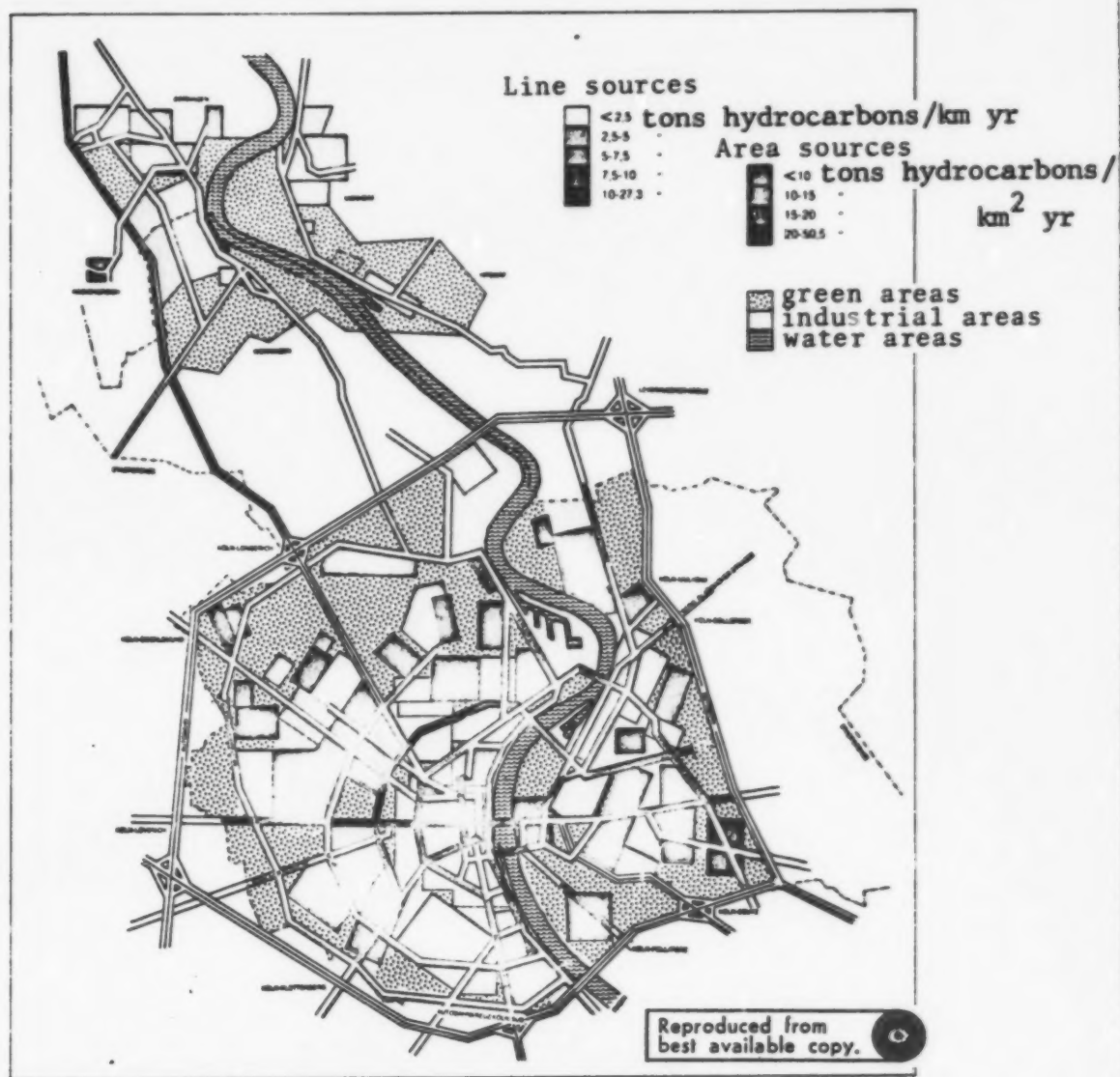


Figure 5 CH emission density for the city of Cologne and vicinity (vehicular traffic)

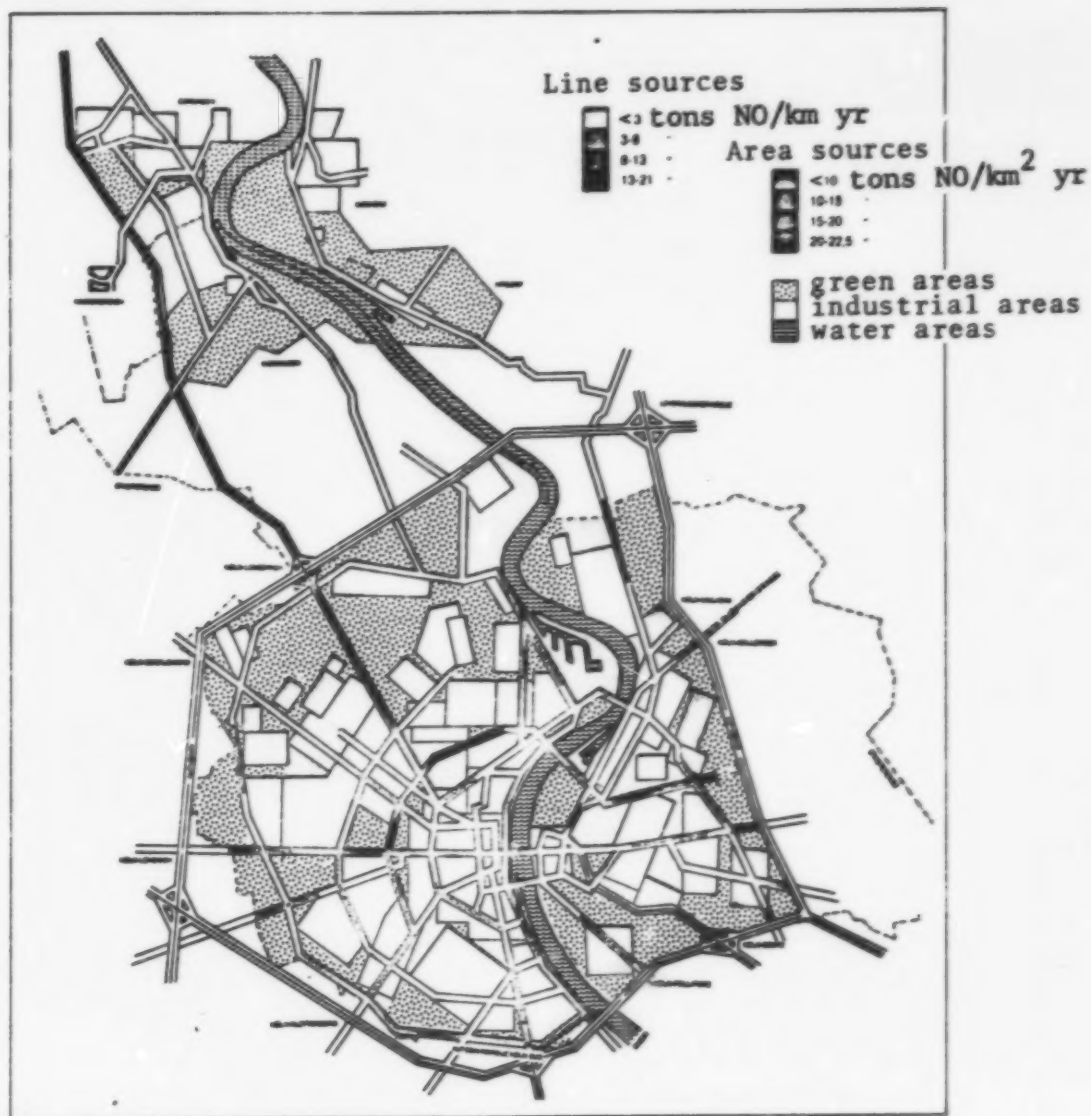


Figure 6 NO emission density for the city of Cologne and vicinity

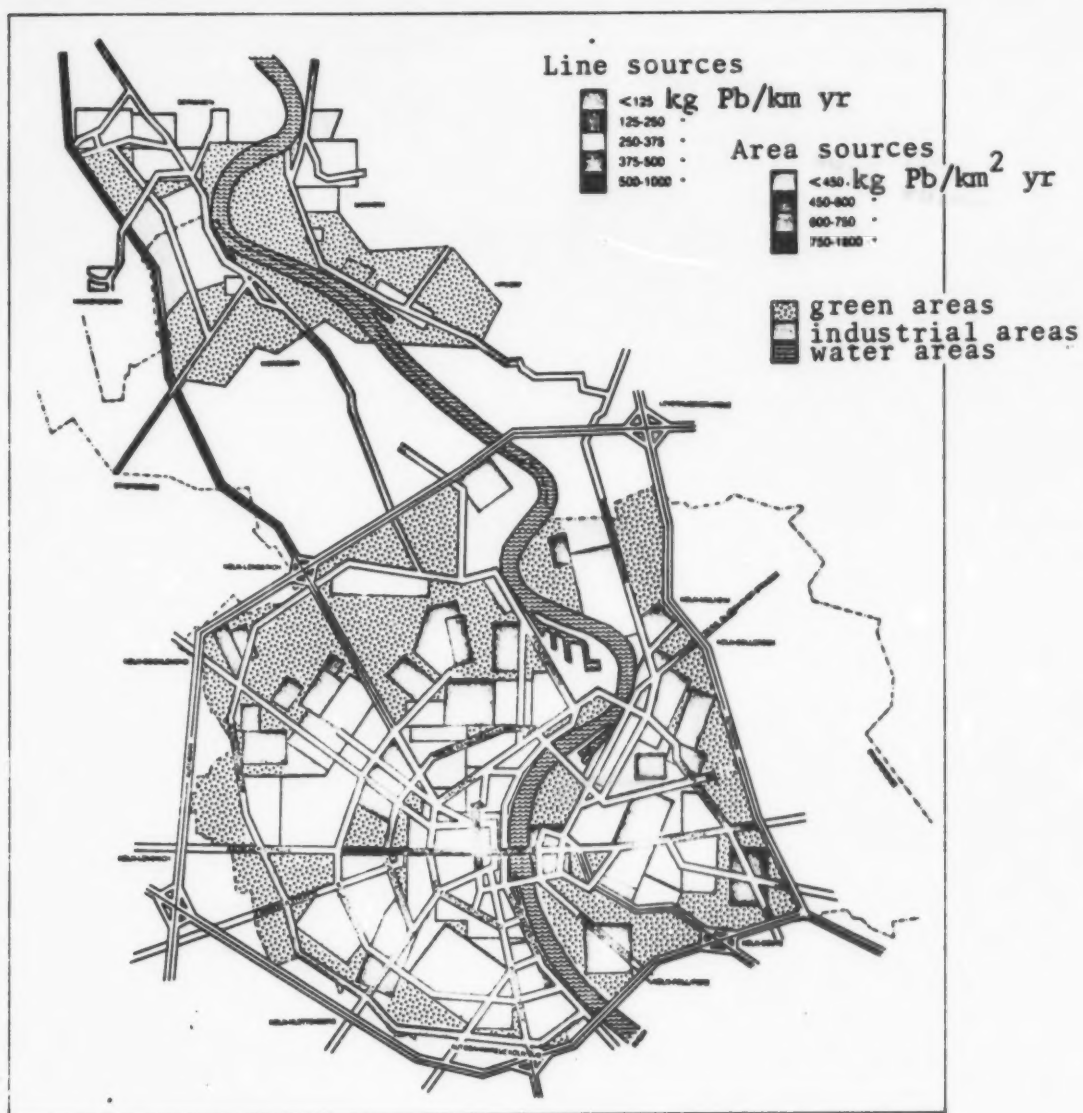


Figure 7 Lead emission density for the city of Cologne and vicinity (vehicular traffic)



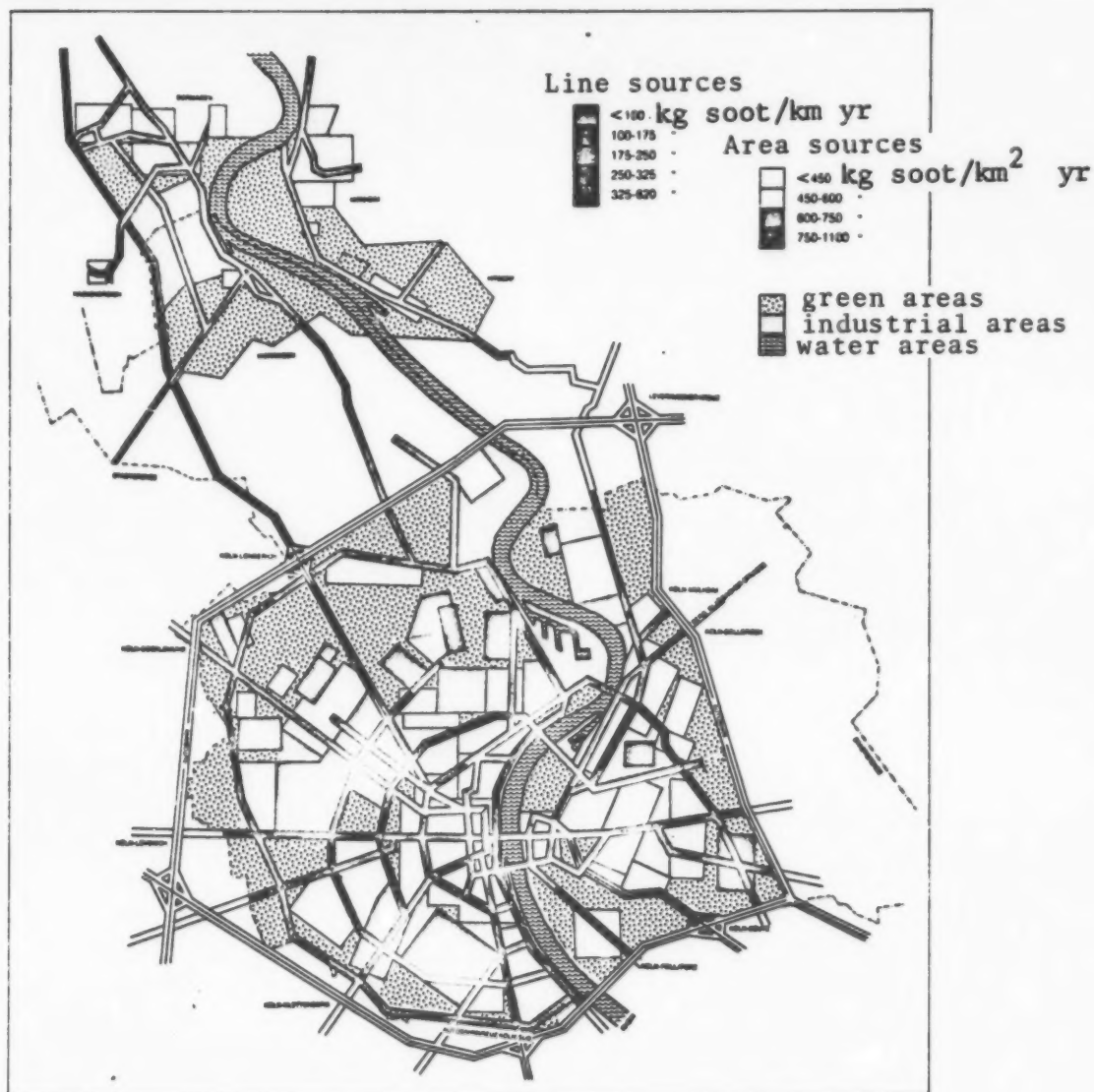


Figure 8 Soot emission density for the city of Cologne and vicinity (vehicular traffic)

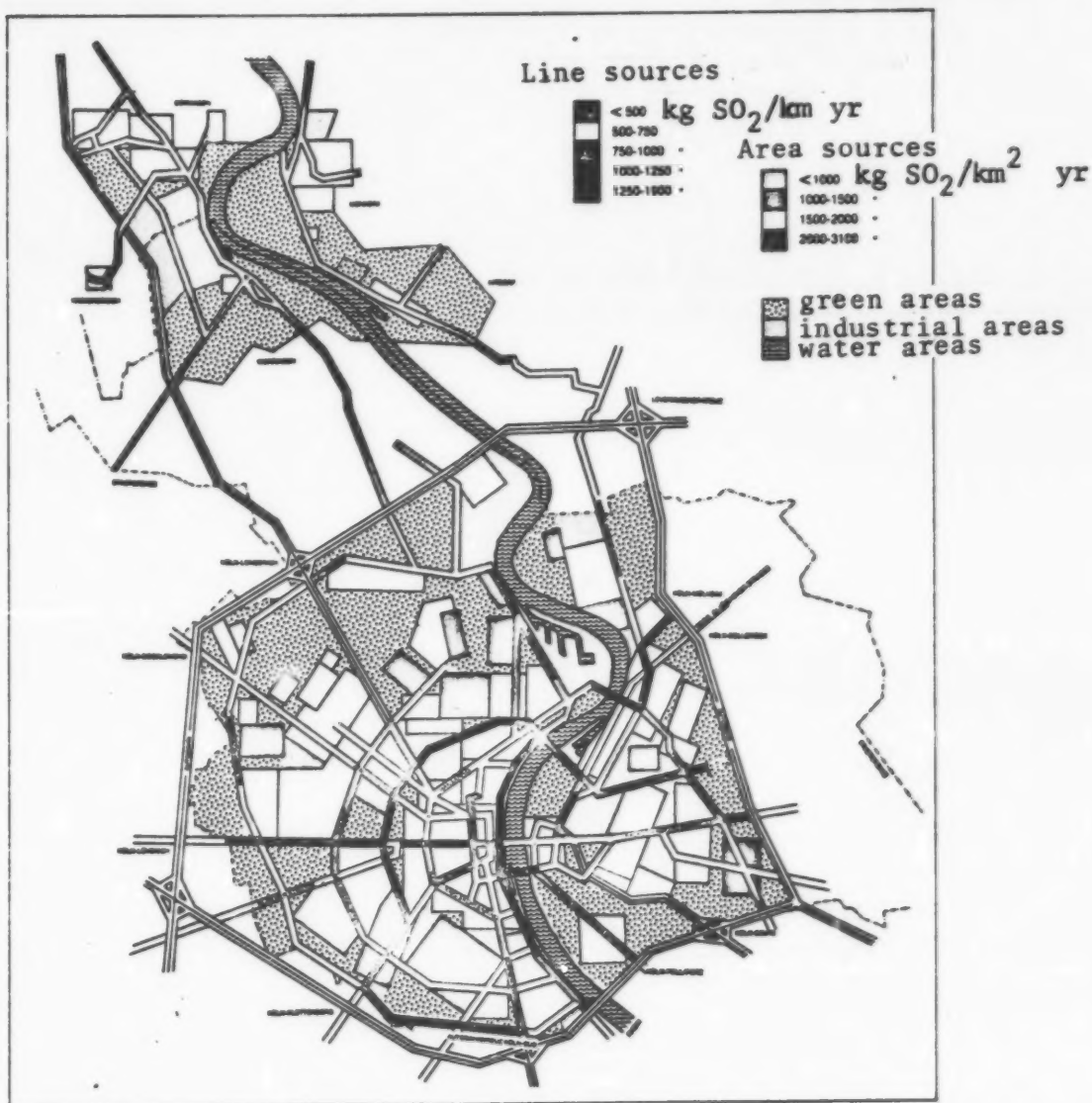
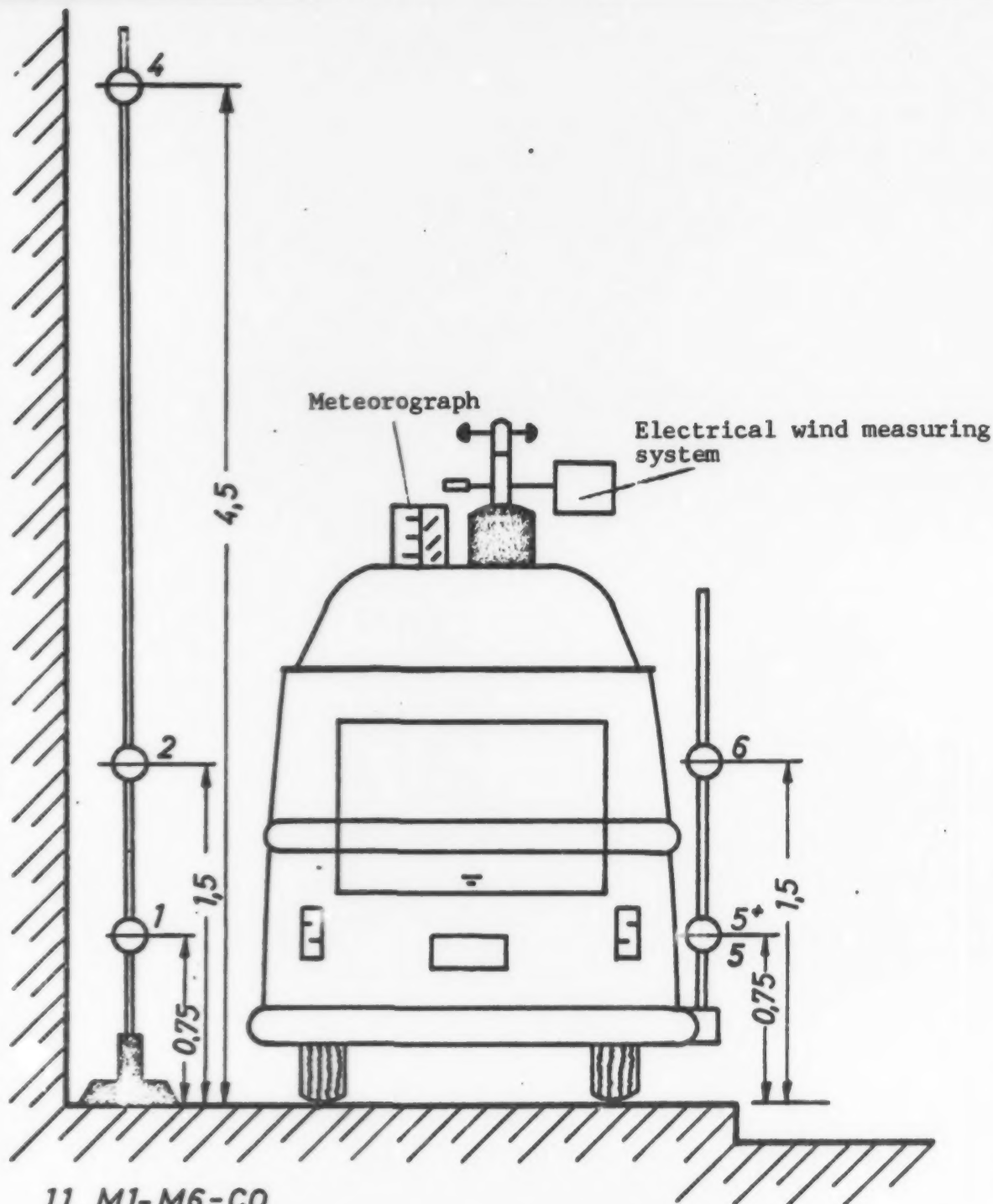


Figure 9 SO<sub>2</sub> emission density for the city of Cologne and vicinity (vehicular traffic)



1.1 M1-M6=CO

1.2 M5\*=CH,SO<sub>2</sub>,NO<sub>x</sub>(and NO<sub>2</sub>)

Figure 10 Design of the measuring truck and arrangement of the instruments

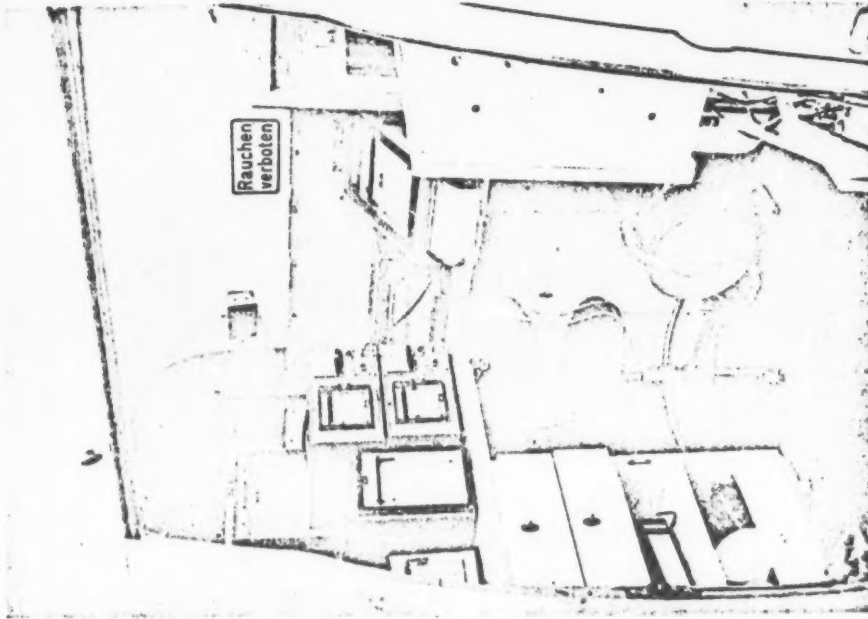


Figure 12 Inside view of the  
measuring truck

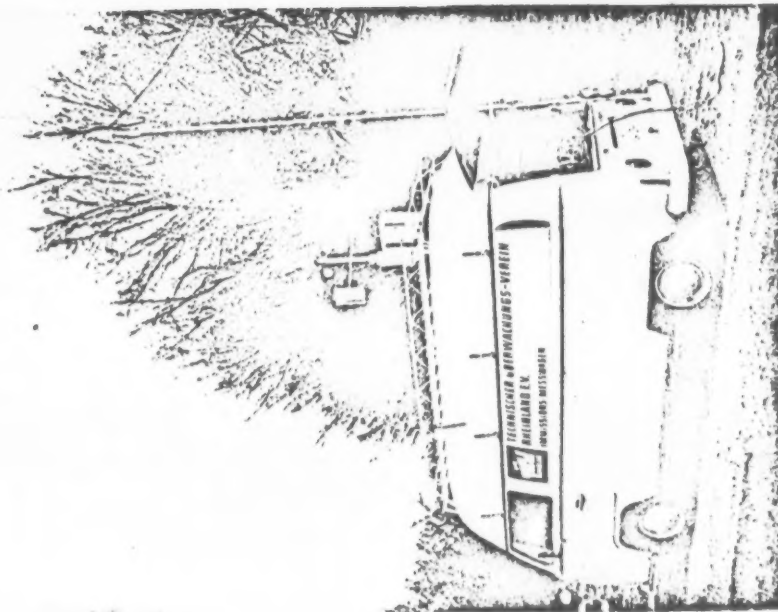
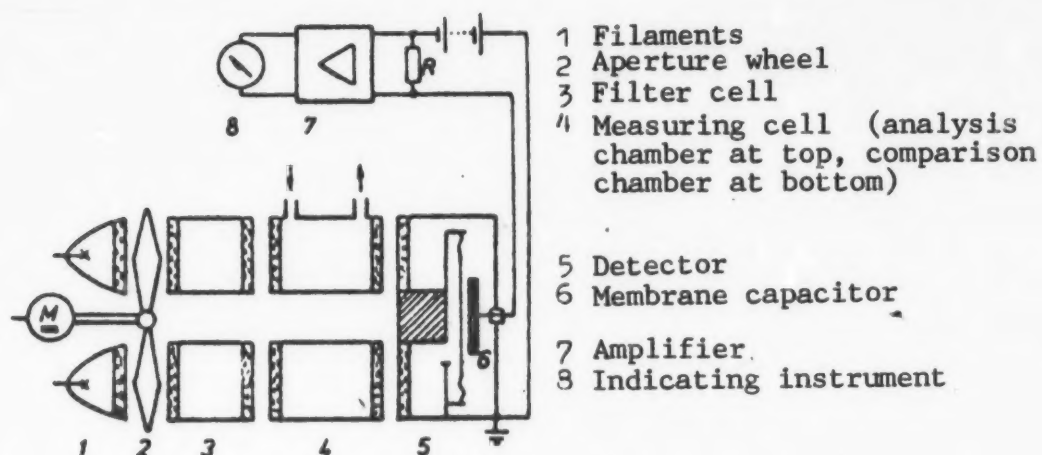


Figure 11 Outside view of the  
measuring truck





#### Description:

In the Uras 2, the specific radiation absorption of polyatomic non-elemental gases in the infrared spectral range serves as the measured effect. The absorption is measured in an alternating beam photometer arrangement with two parallel beam paths and a selectively acting radiation detector filled with the gas component to be determined. The sample gas is led through the analysis chamber in the measuring beam path. The comparison chamber in the second beam path contains nitrogen, which absorbs no infrared radiation. The difference in the radiations leaving the chambers, due to the absorption in the analysis chamber, causes different heating and, thus, a pressure difference in the two detector chambers. The pressure difference is determined by a membrane capacitor and converted into an electrical signal which passes through an amplifier

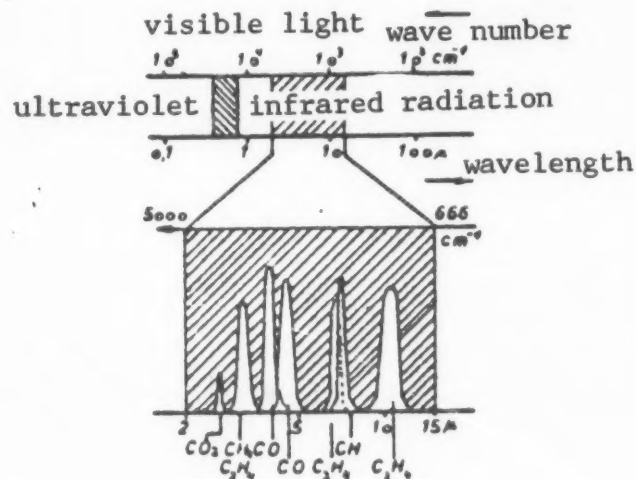


Figure 13 Design and operation of the CO analyzer

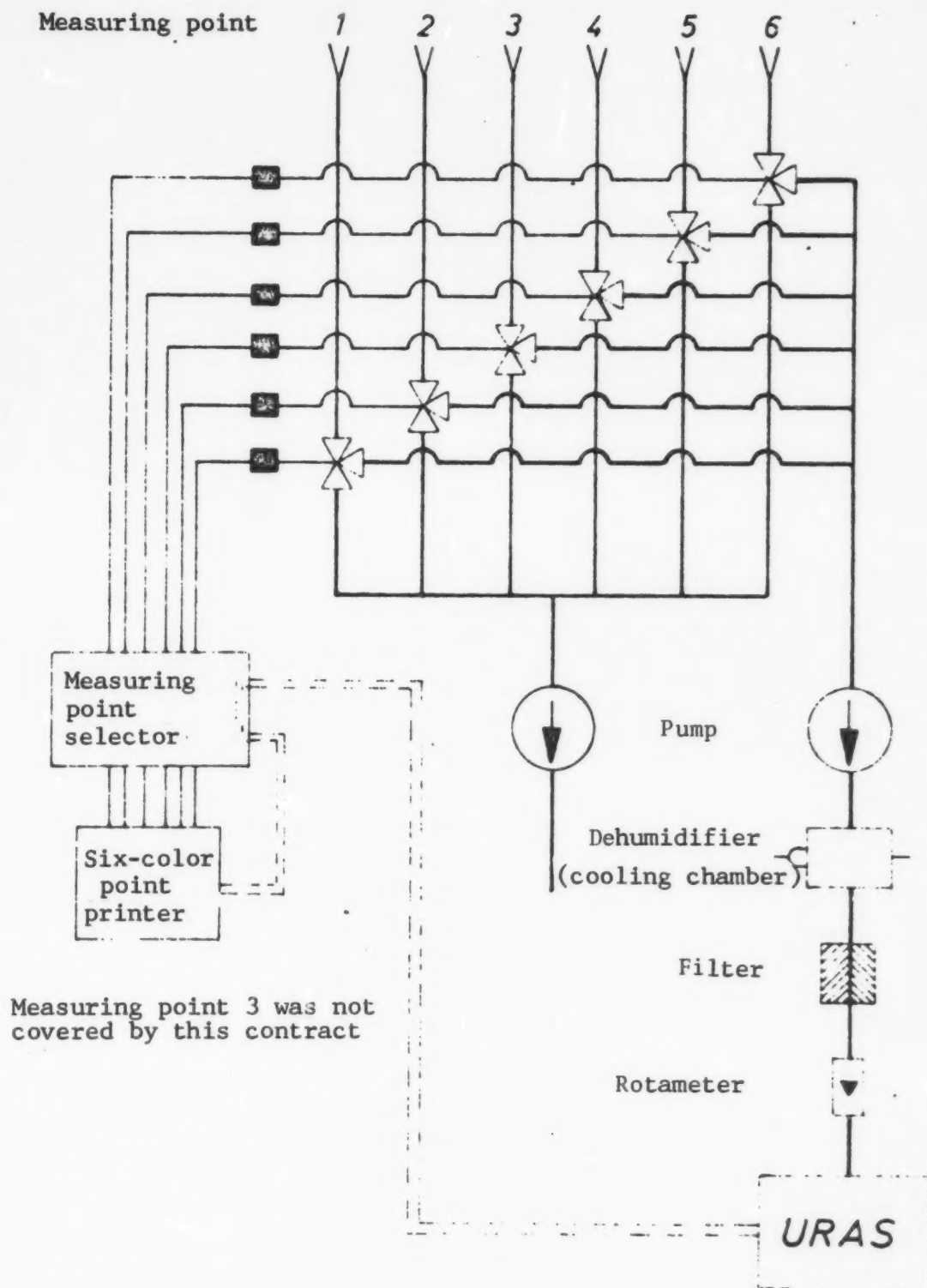


Figure 14 Switching plan for CO measurement

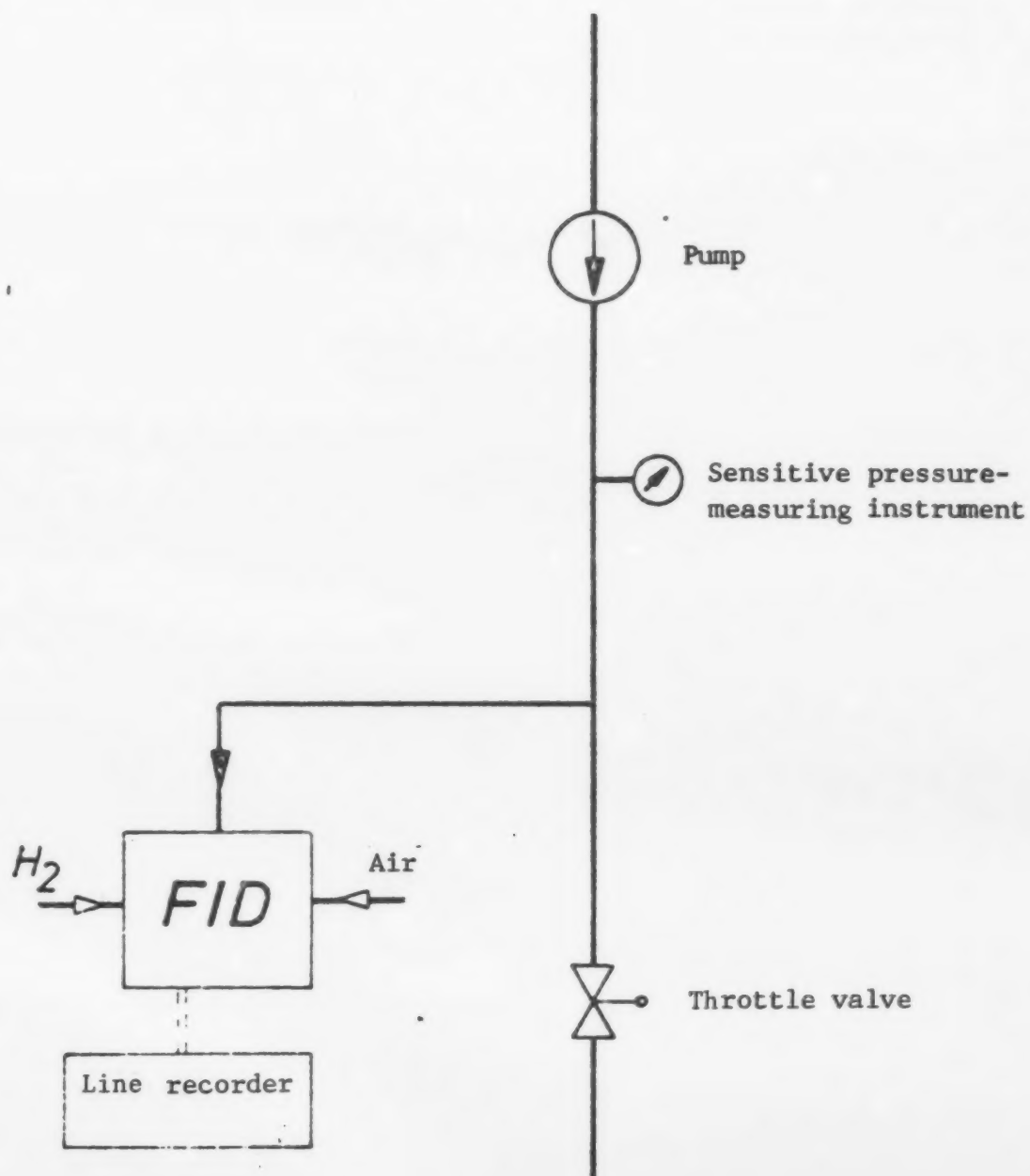
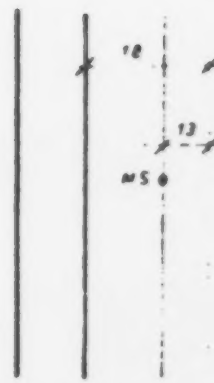
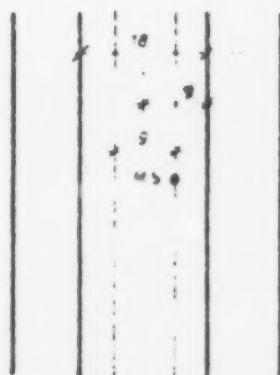
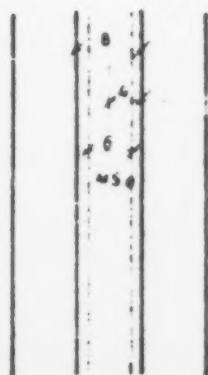
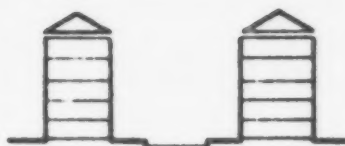


Figure 15 Switching plan for  $C_nH_m$  measurement

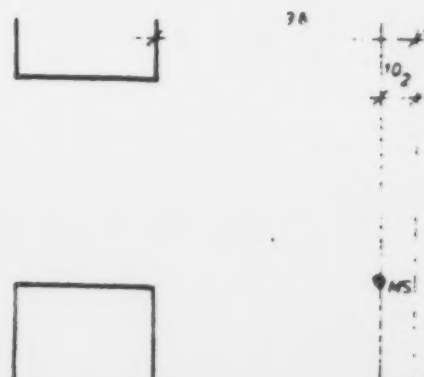
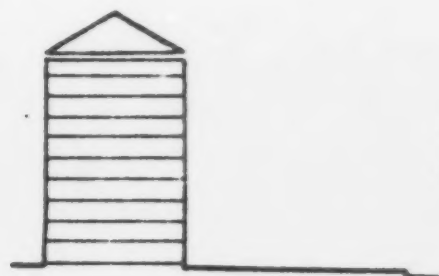


Model 1

Model 2

Model 6

MS = Immission Site



Model 4

Model 10

Figure 16 Geometric dimensions of the street types covered by immission measurements





Figure 17 Map of measuring sites

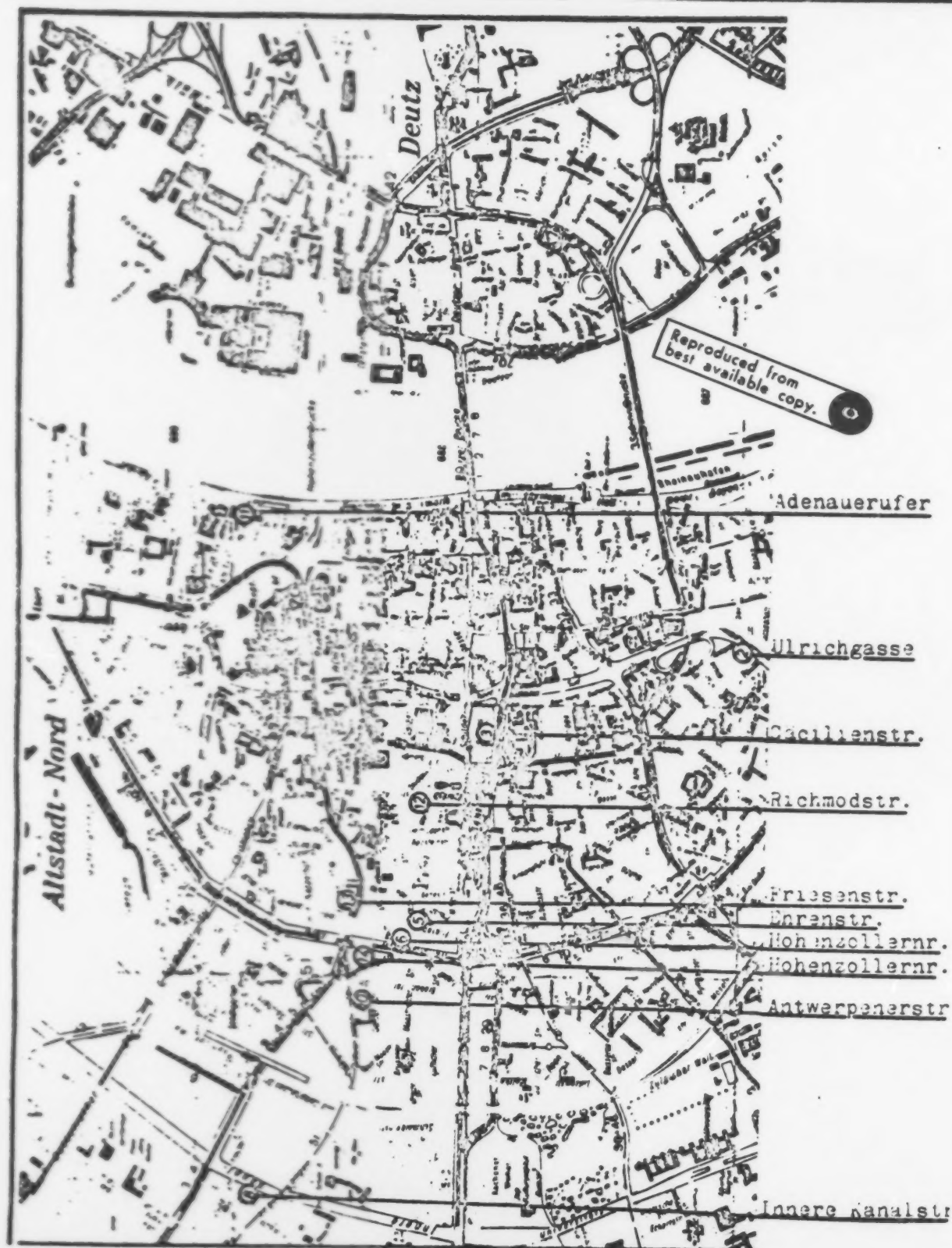
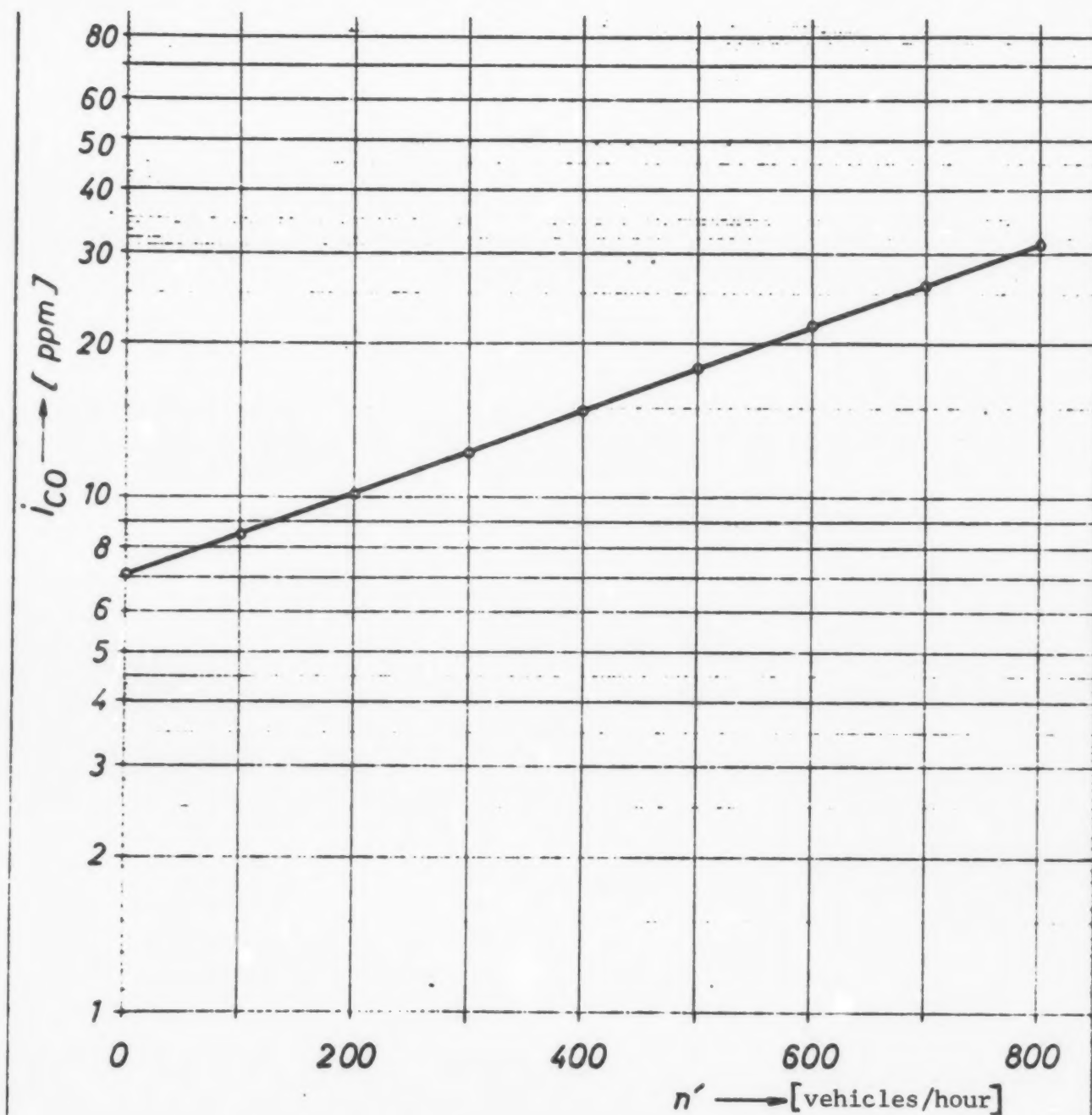
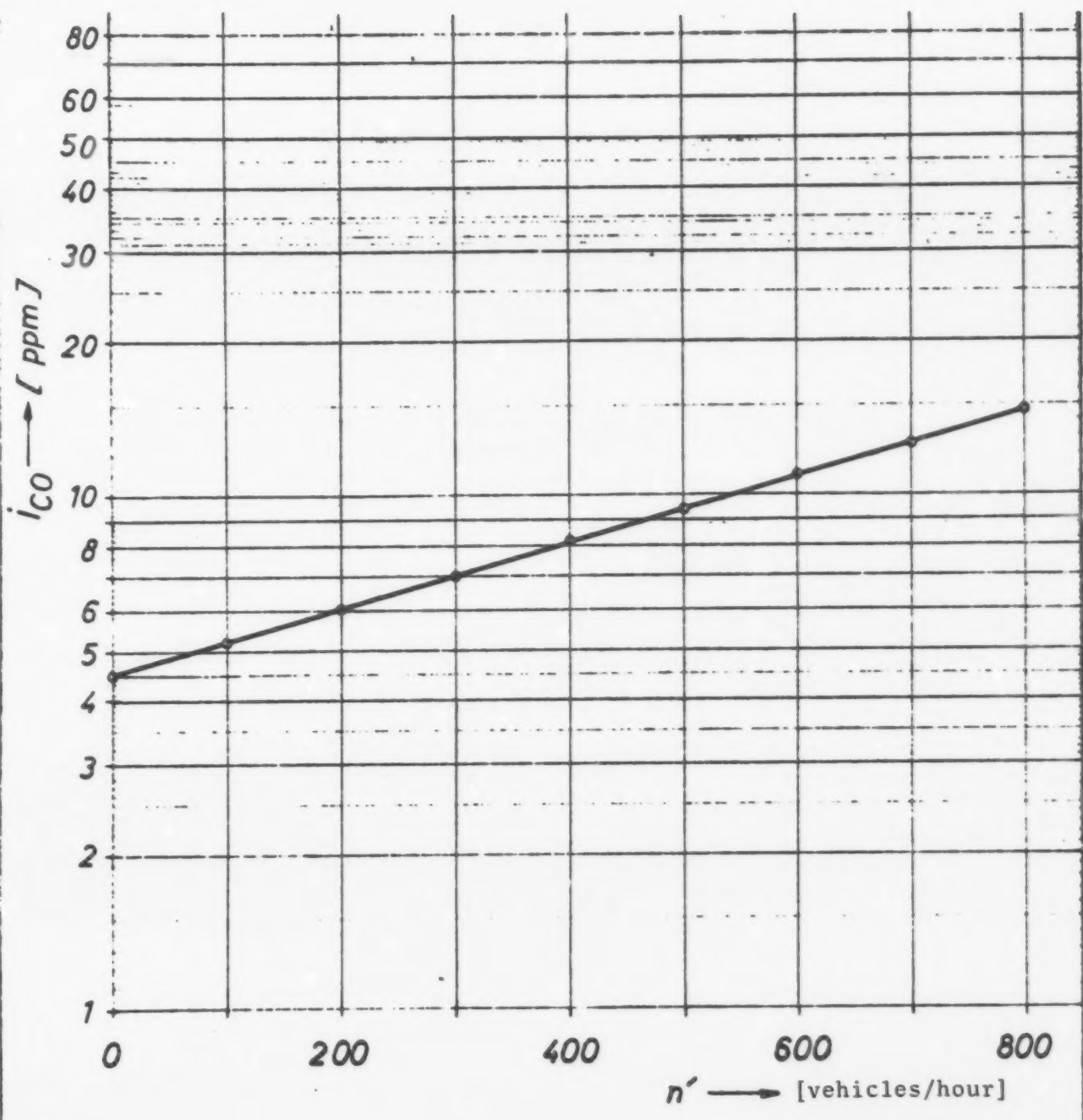


Figure 18 Map of measuring sites (inner city)



wind speed: **0 - 3 m/s**

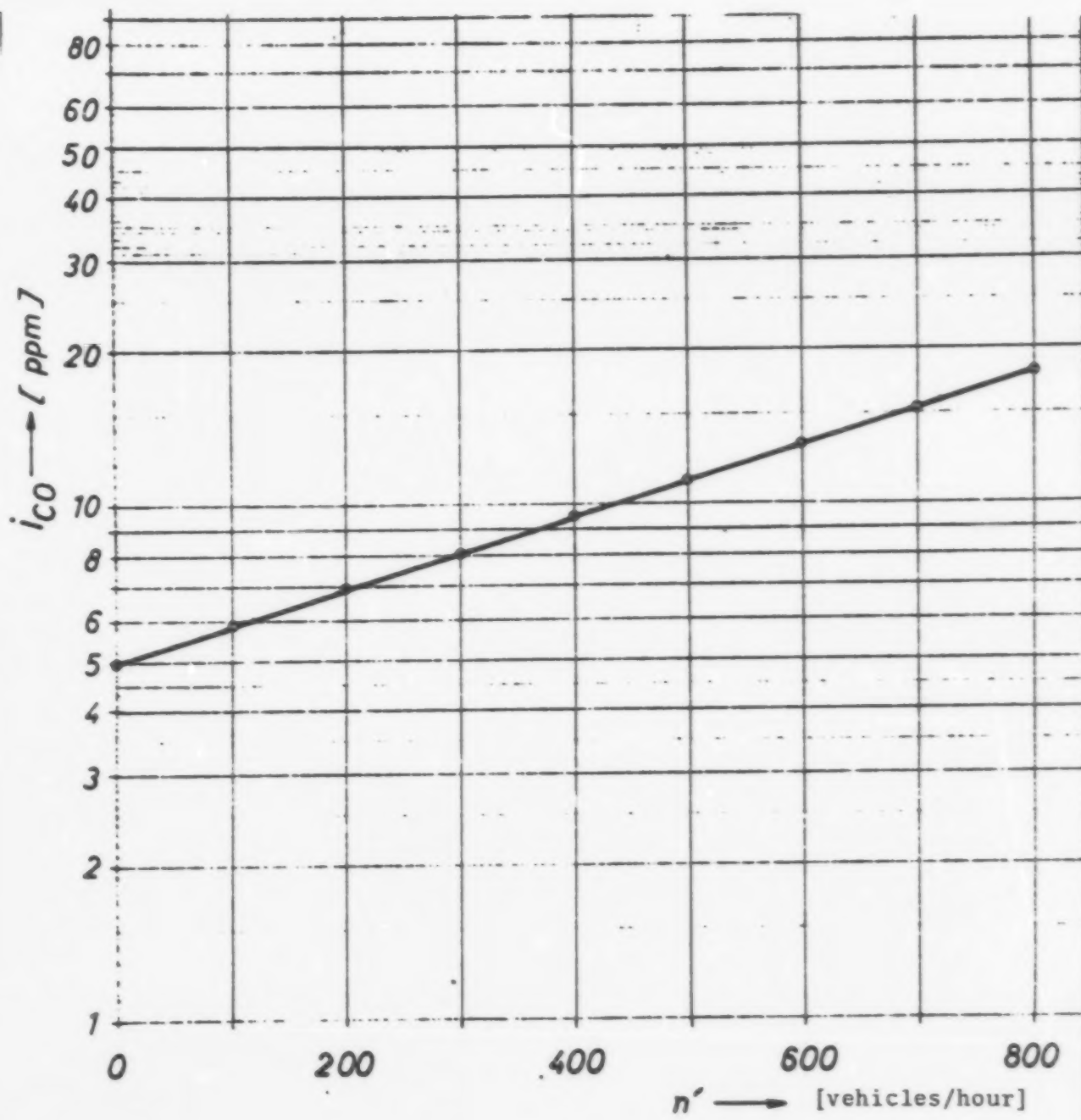
Figure 19 Dependence of CO concentration on traffic, street model 1, upwind



wind speed:  $>3\text{ m/s}$

Figure 20 Dependence of CO concentration on traffic, street model 1, upwind

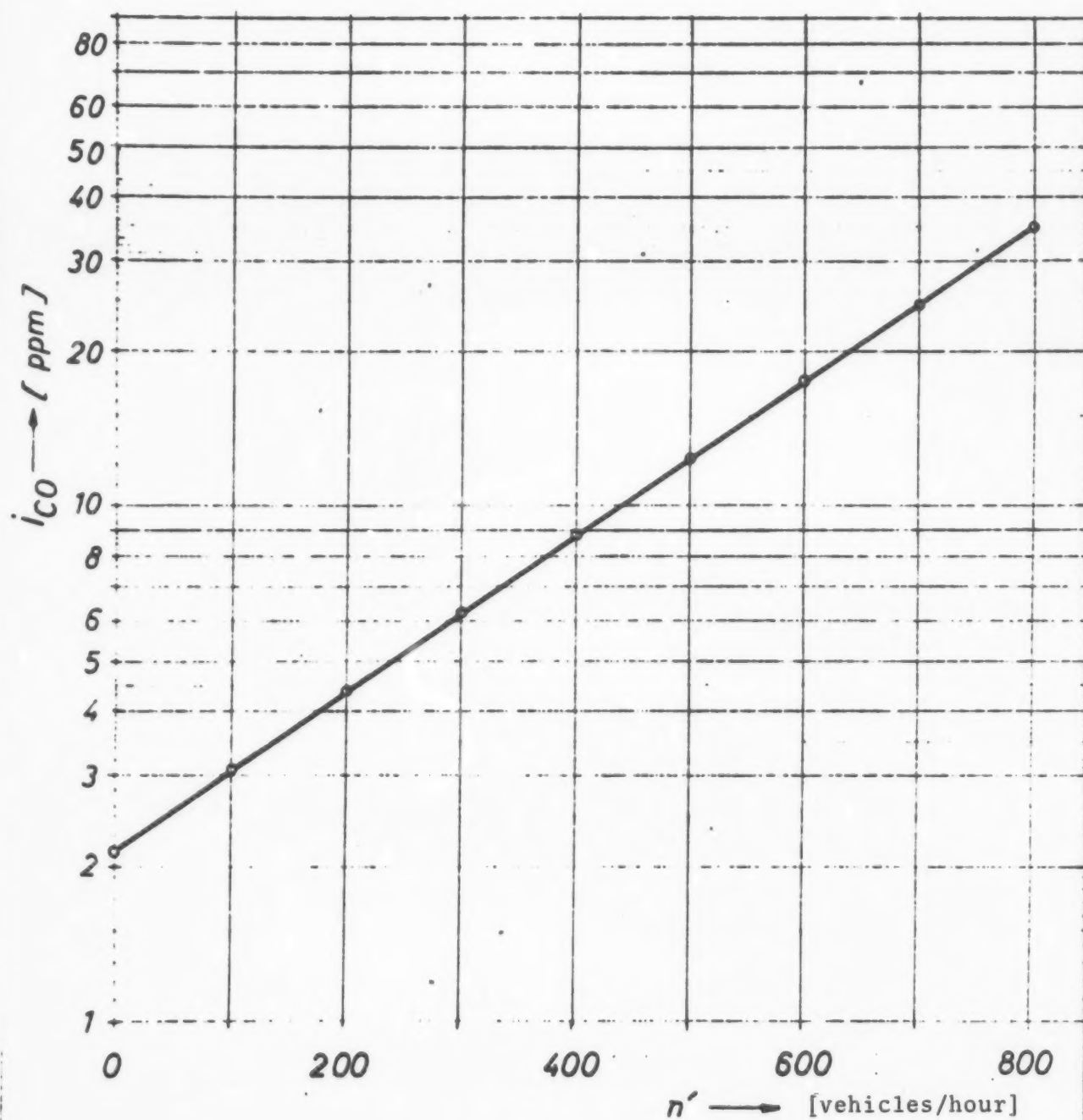




wind speed:  $0-\infty$  m/s

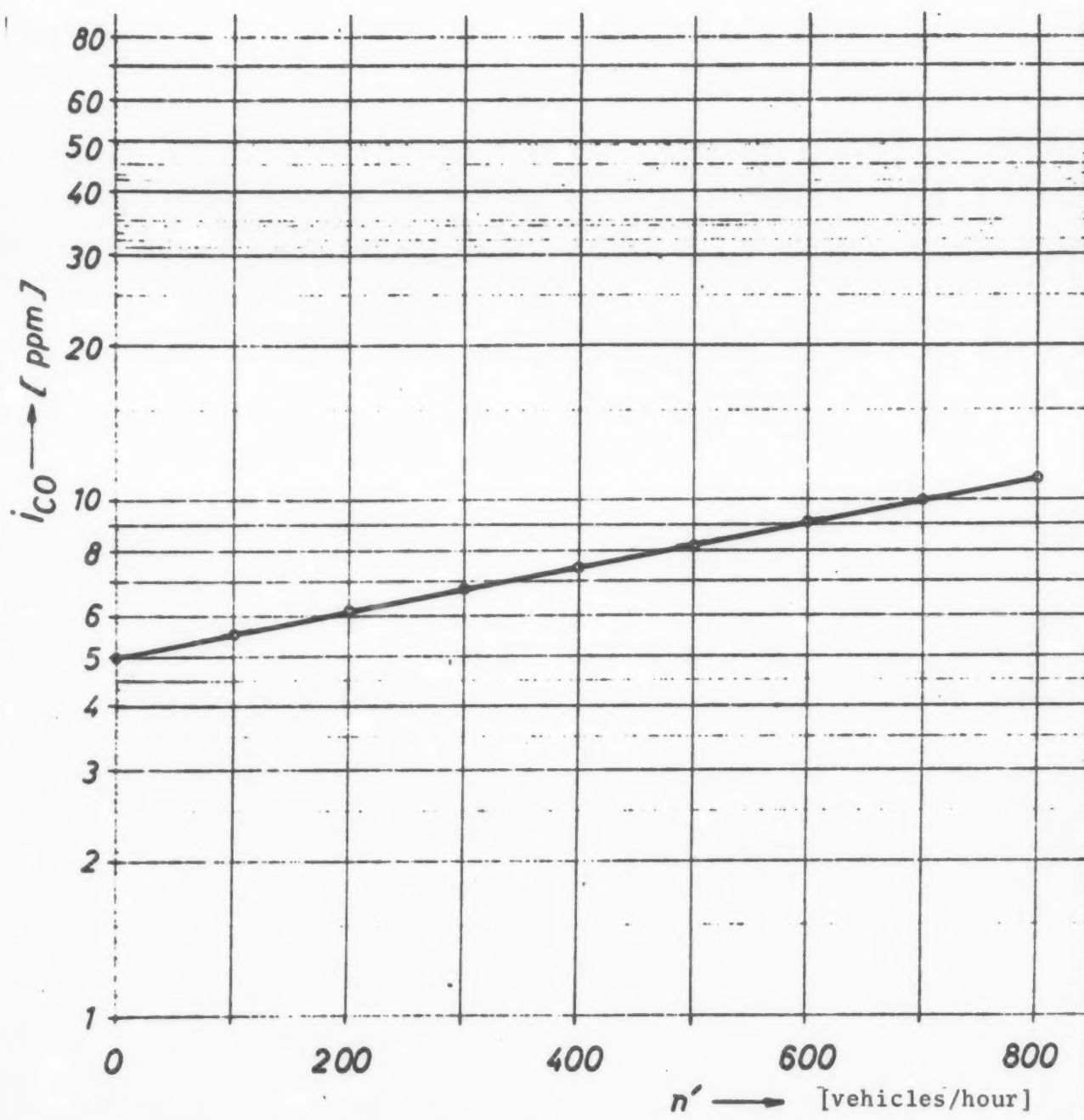
Figure 21 Dependence of CO concentration on traffic, street model 1, upwind





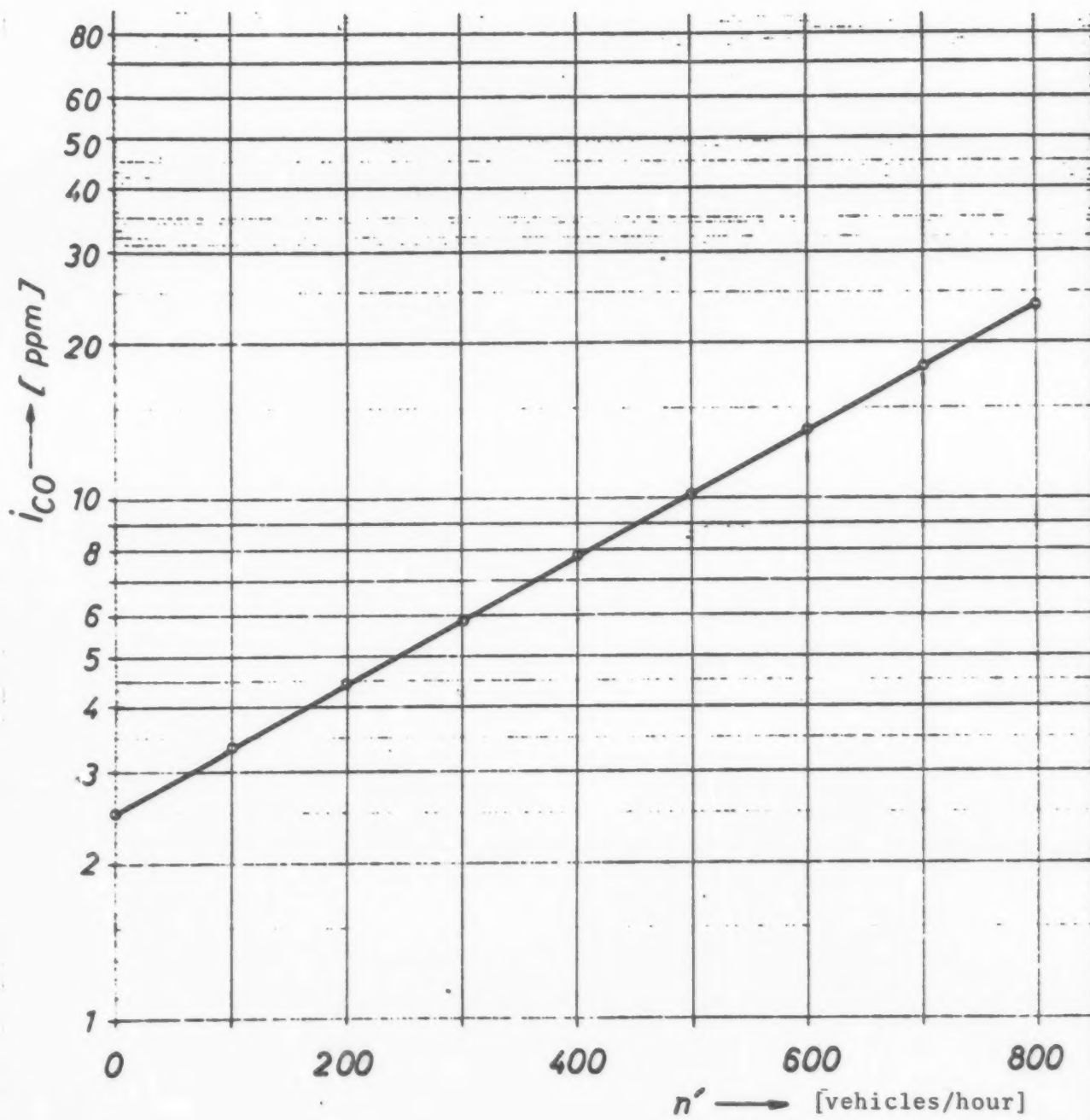
wind speed: 0 - 3 m/s

Figure 22 Dependence of the CO concentration on traffic, street model 1, downwind



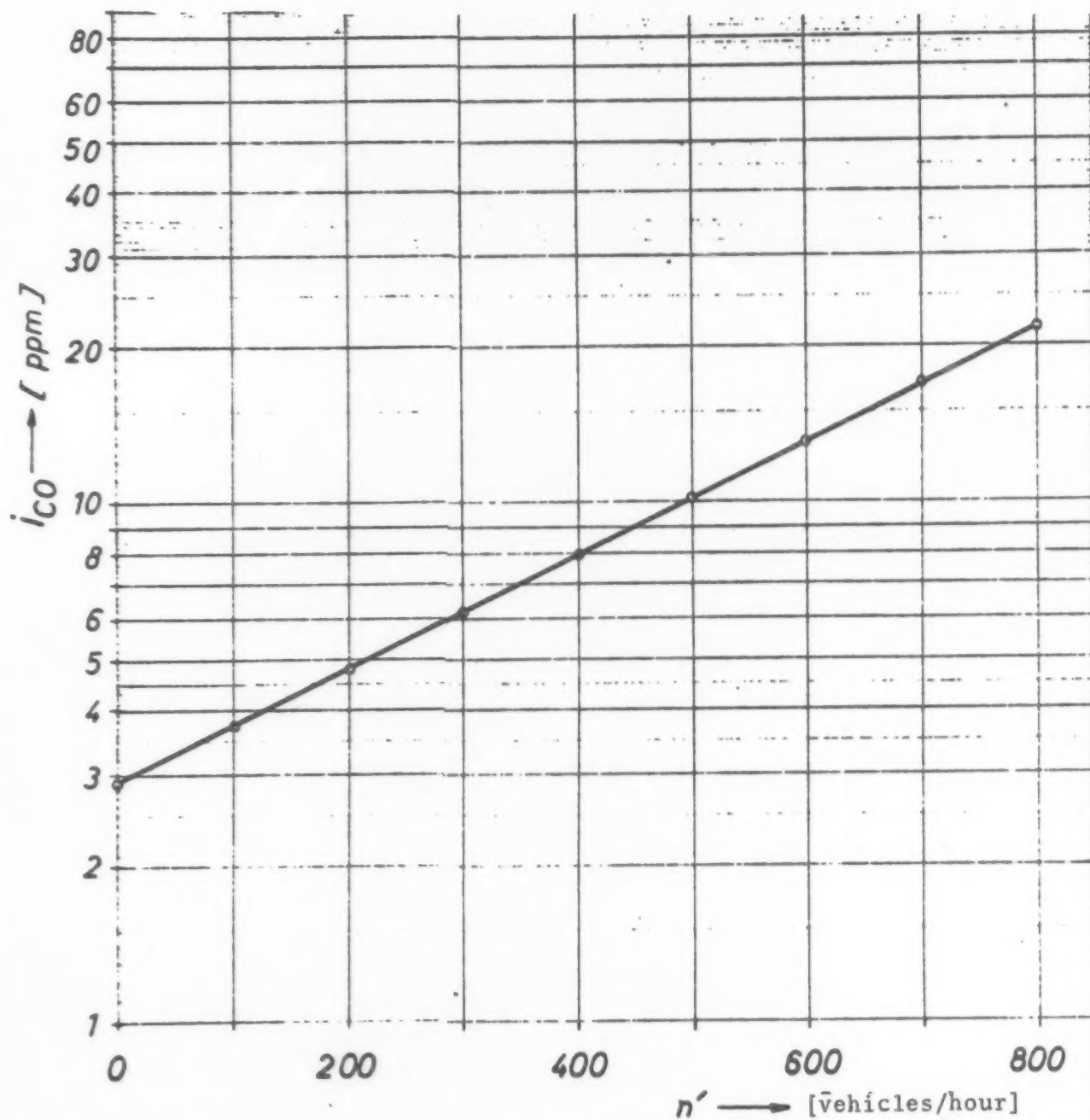
wind speed:  $>3 \text{ m/s}$

Figure 23 Dependence of CO concentration on traffic,  
street model 1, downwind



wind speed:  $0-\infty$  m/s

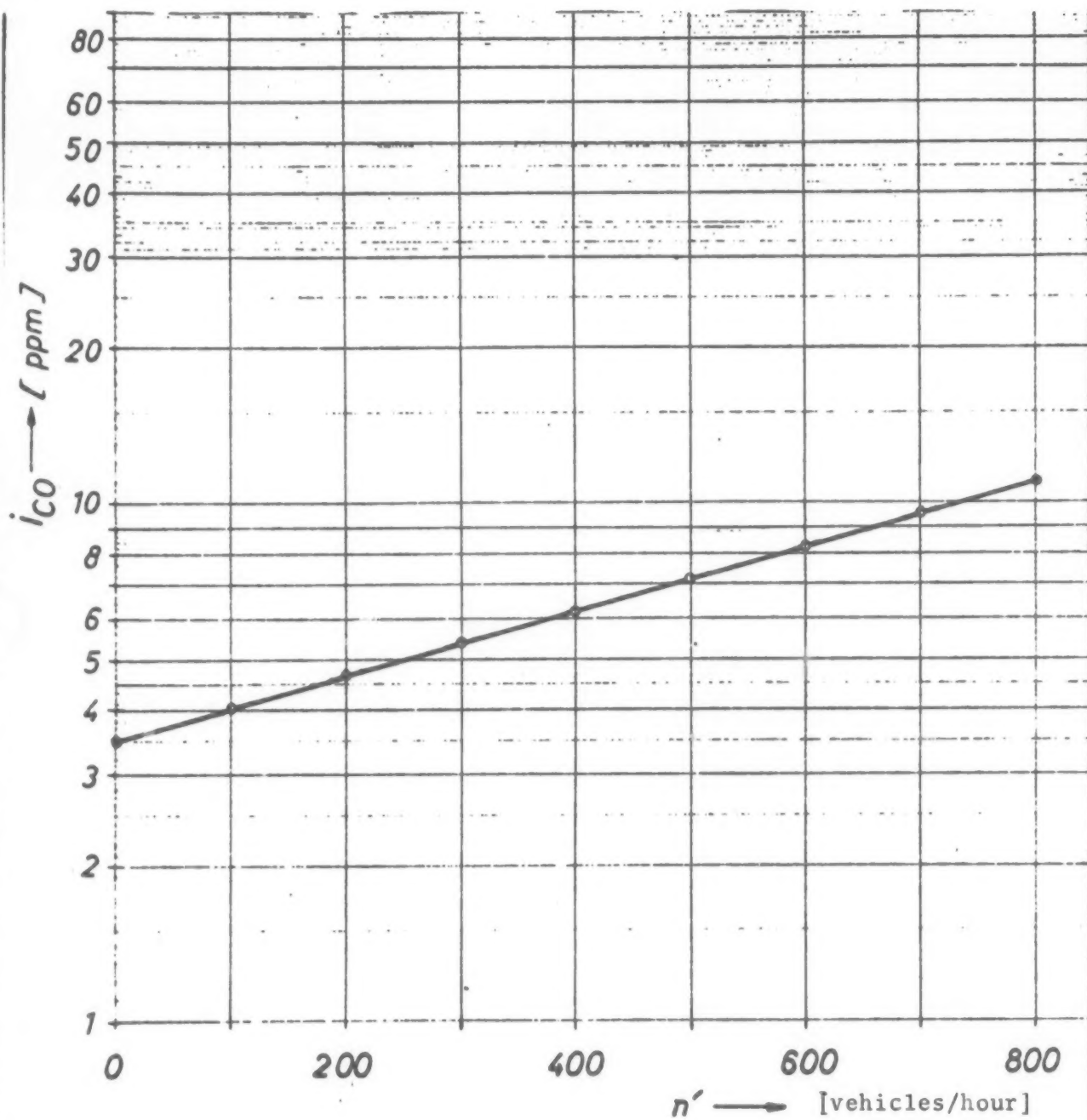
Figure 24 Dependence of CO concentration on traffic, street model 1, downwind



wind speed: 0 - 3 m/s

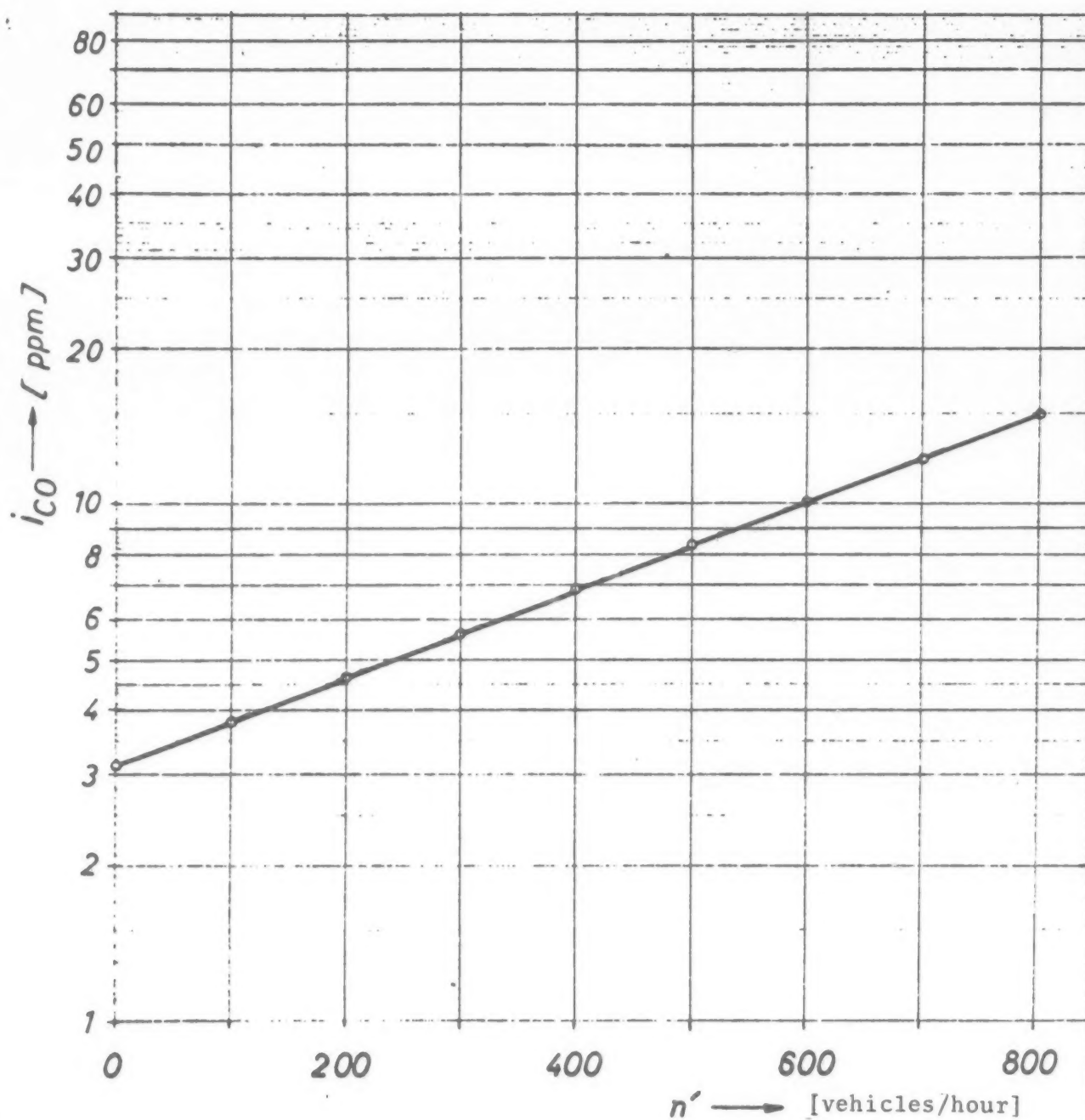
Figure 25 Dependence of CO concentration on traffic, street model 1, wind in the street direction





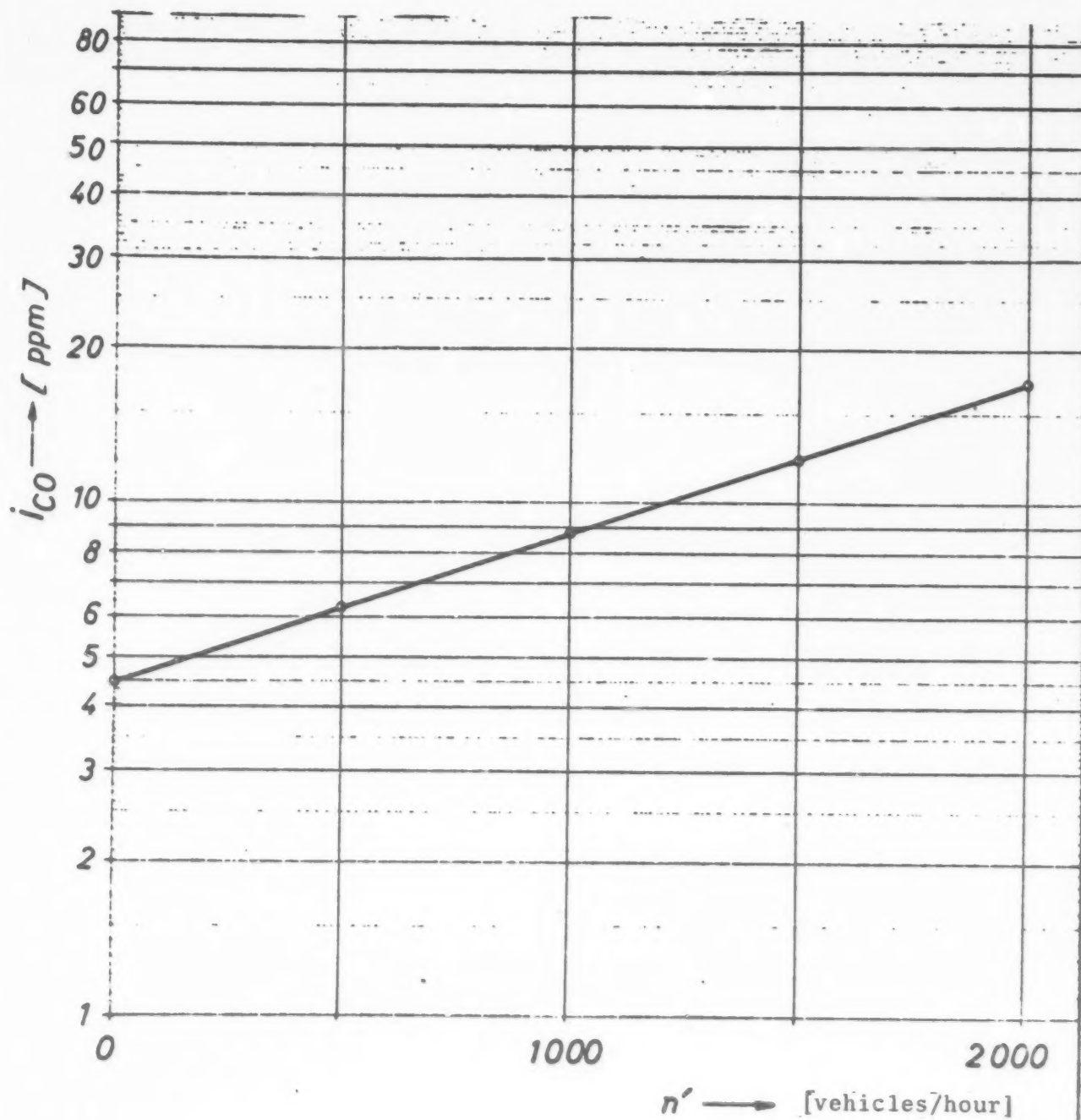
wind speed:  $>3 \text{ m/s}$

Figure 26 Dependence of CO concentration on traffic,  
street model 1, wind in the street direction



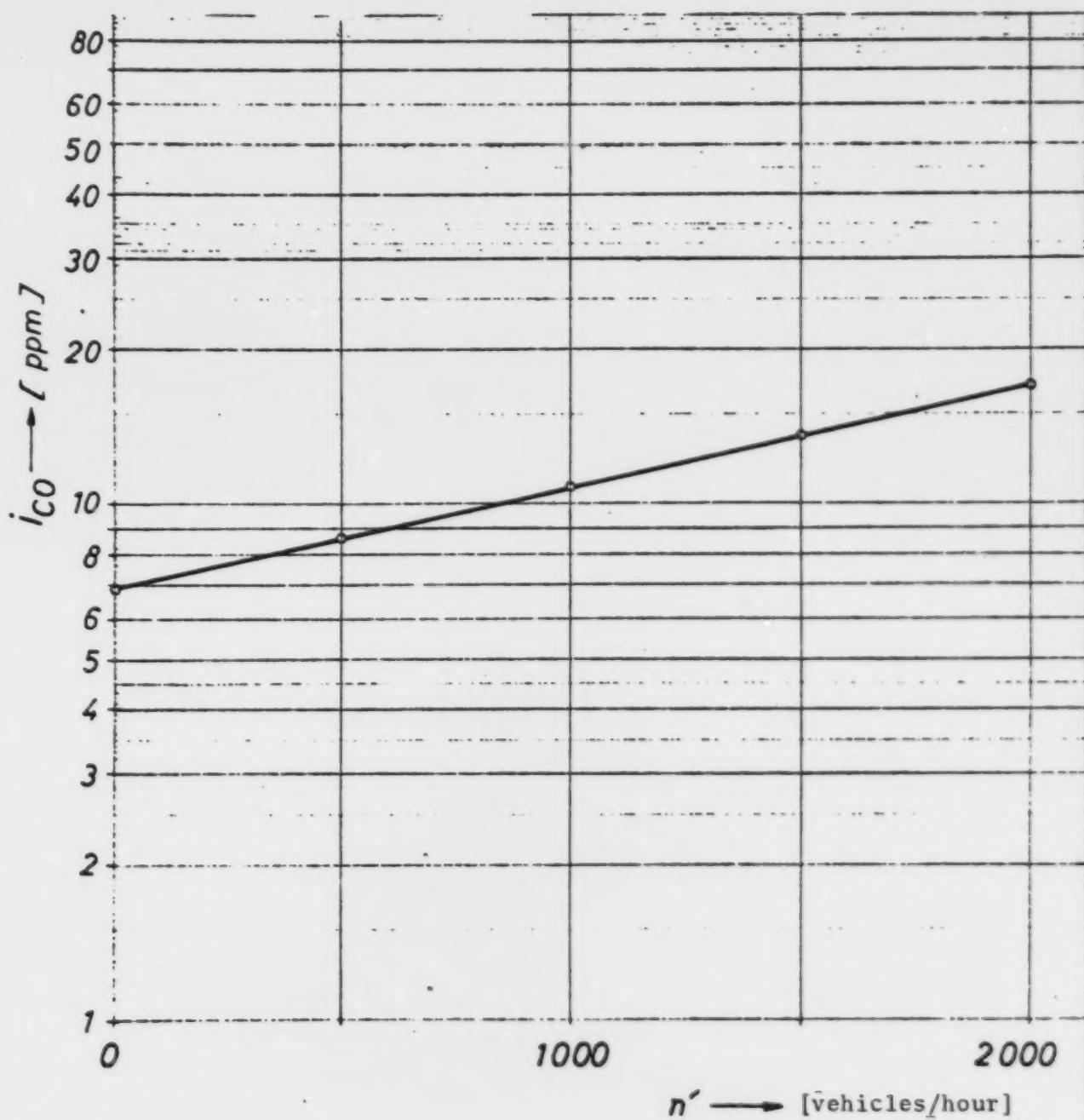
wind speed:  $0-\infty$  m/s

Figure 27 Dependence of the CO concentration on traffic, street model 1, wind in the street direction.



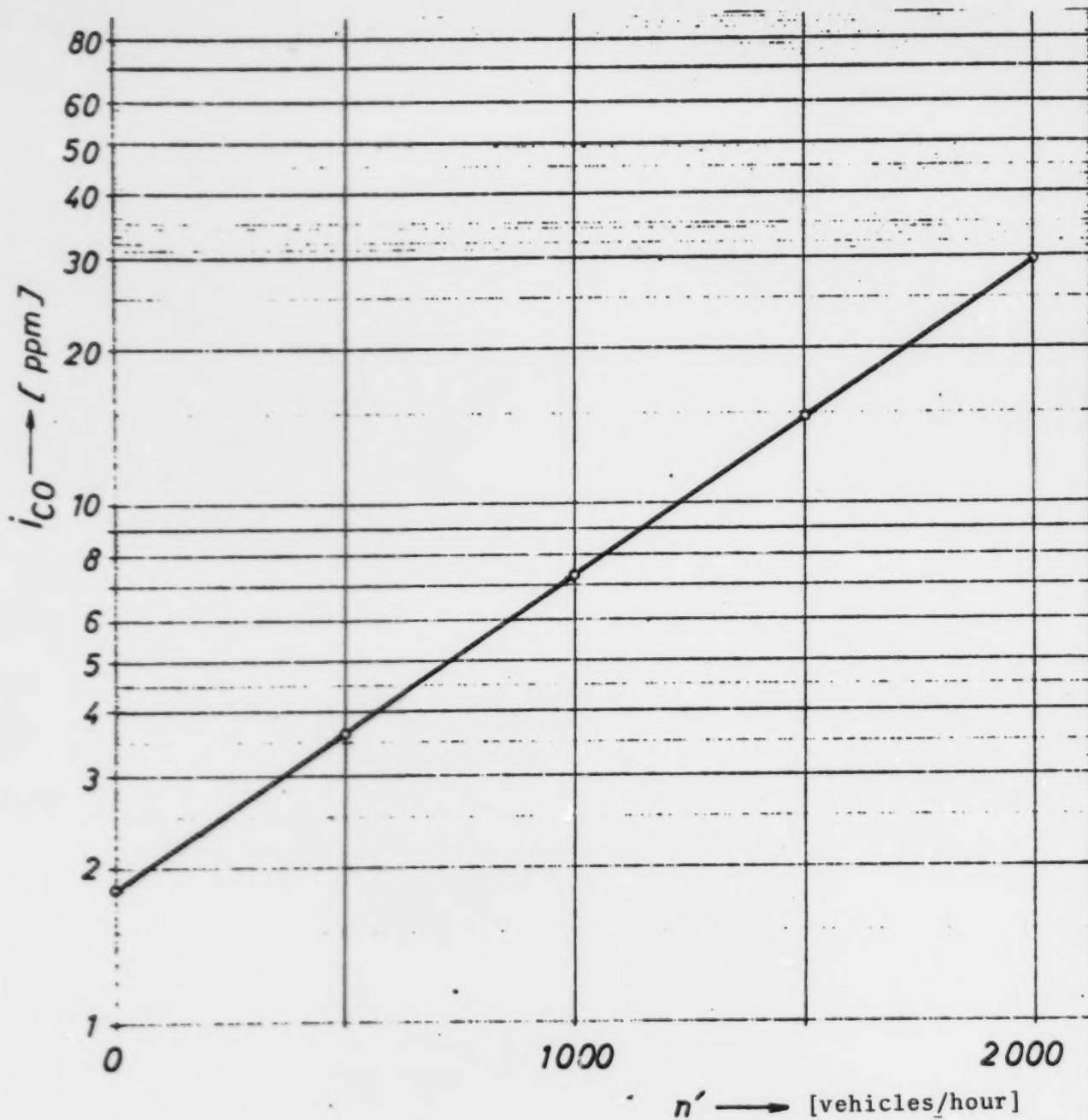
wind speed: **>3 m/s**

Figure 28 Dependence of the CO concentration on traffic,  
street model 2, upwind



wind speed:  $0-\infty$  m/s

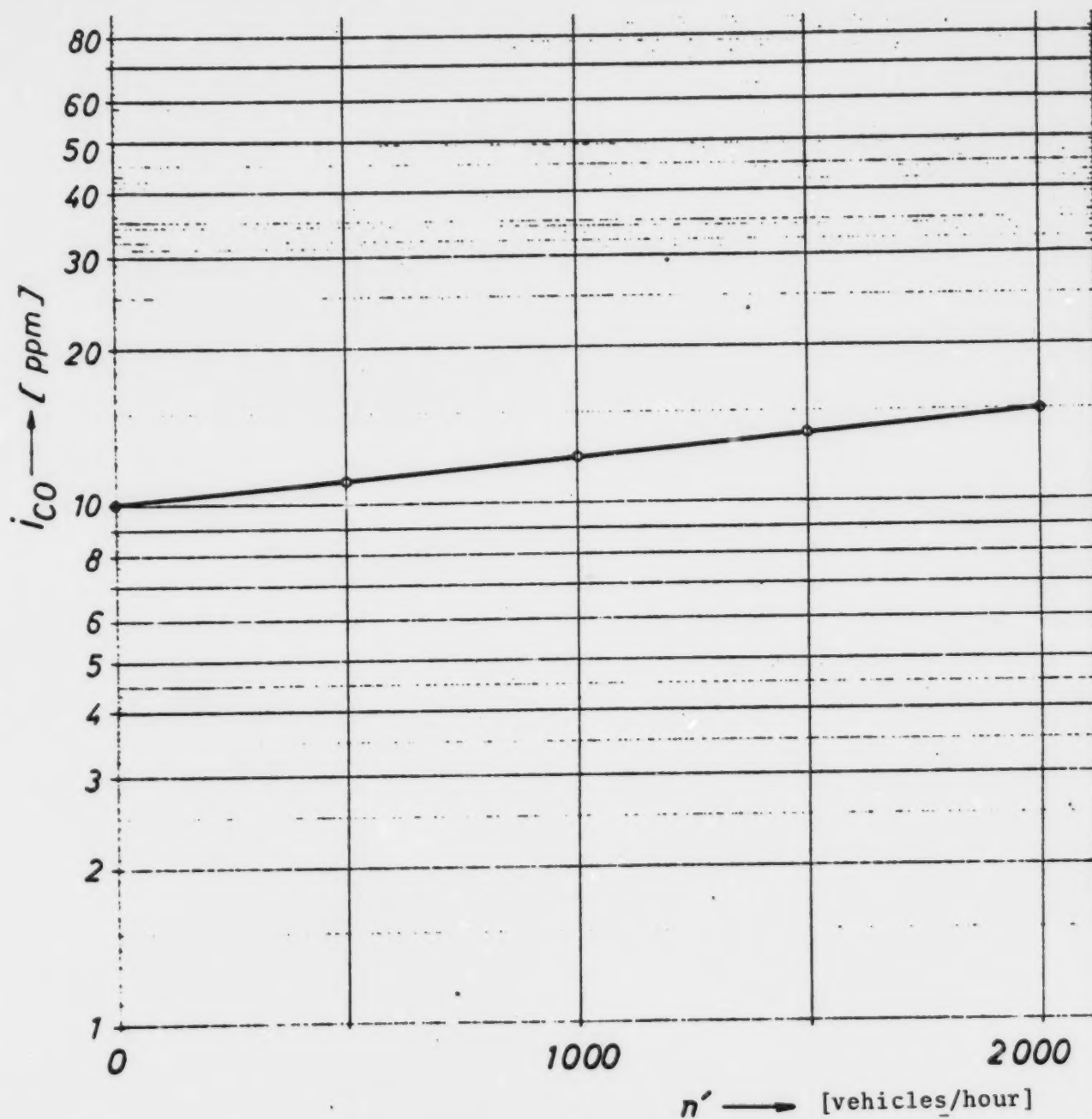
Figure 29 Dependence of CO concentration on traffic,  
street model 2, upwind



wind speed: **0-3 m/s**

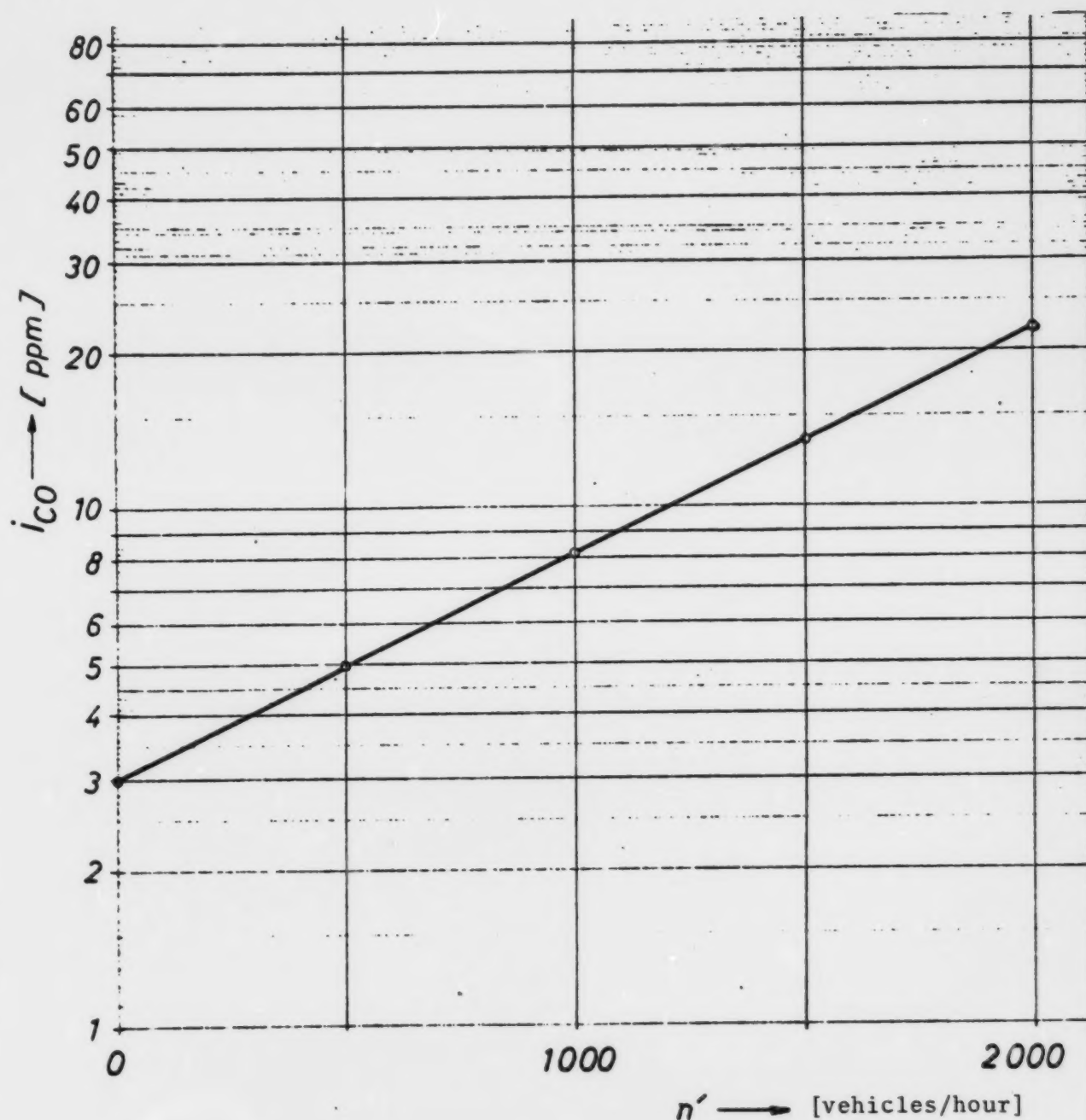
**Figure 30** Dependence of the CO concentration on traffic, street model 2, wind in street direction





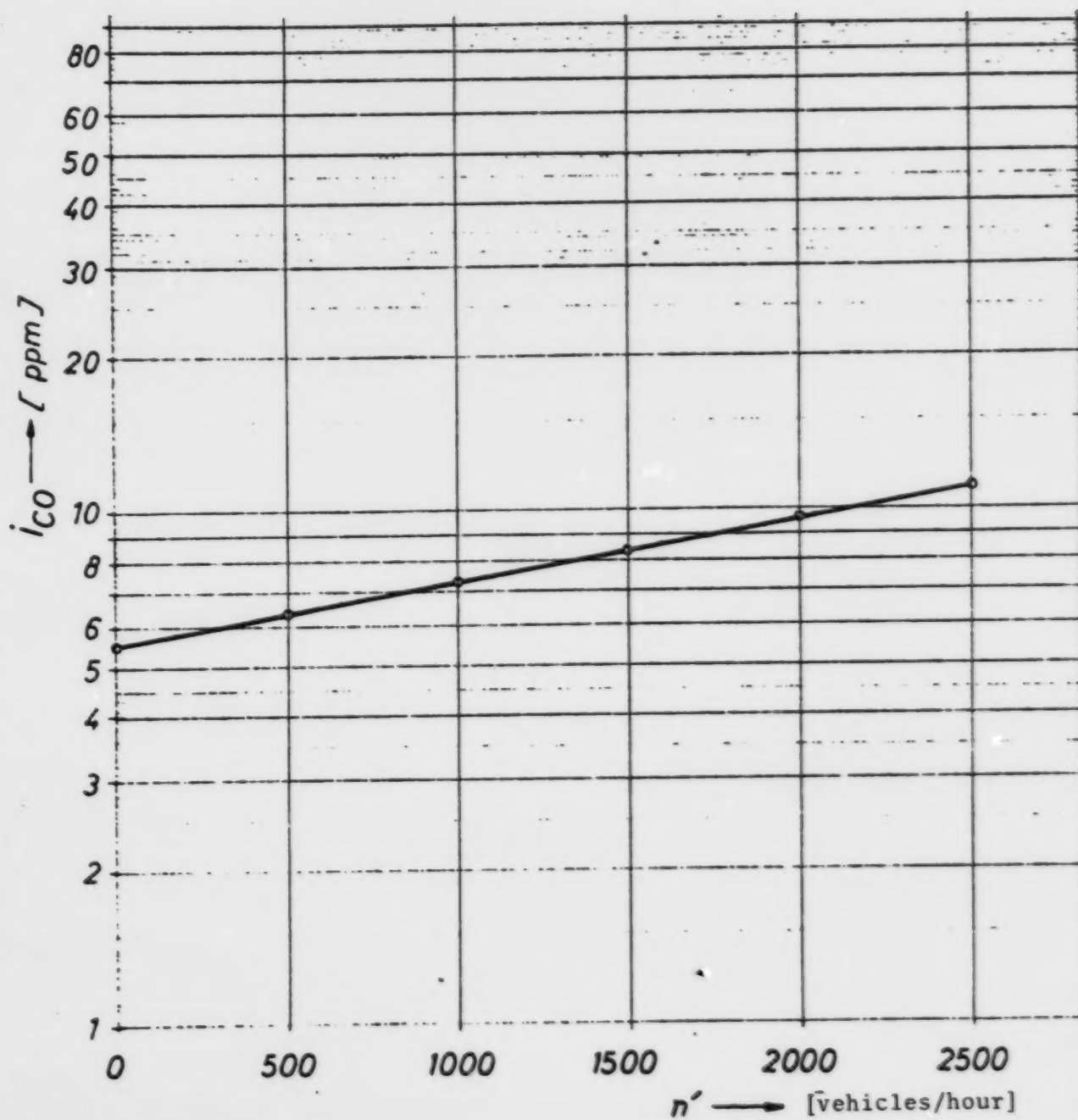
wind speed:  $>3 \text{ m/s}$

Figure 31 Dependence of CO concentration on traffic,  
street model 2, wind in street direction



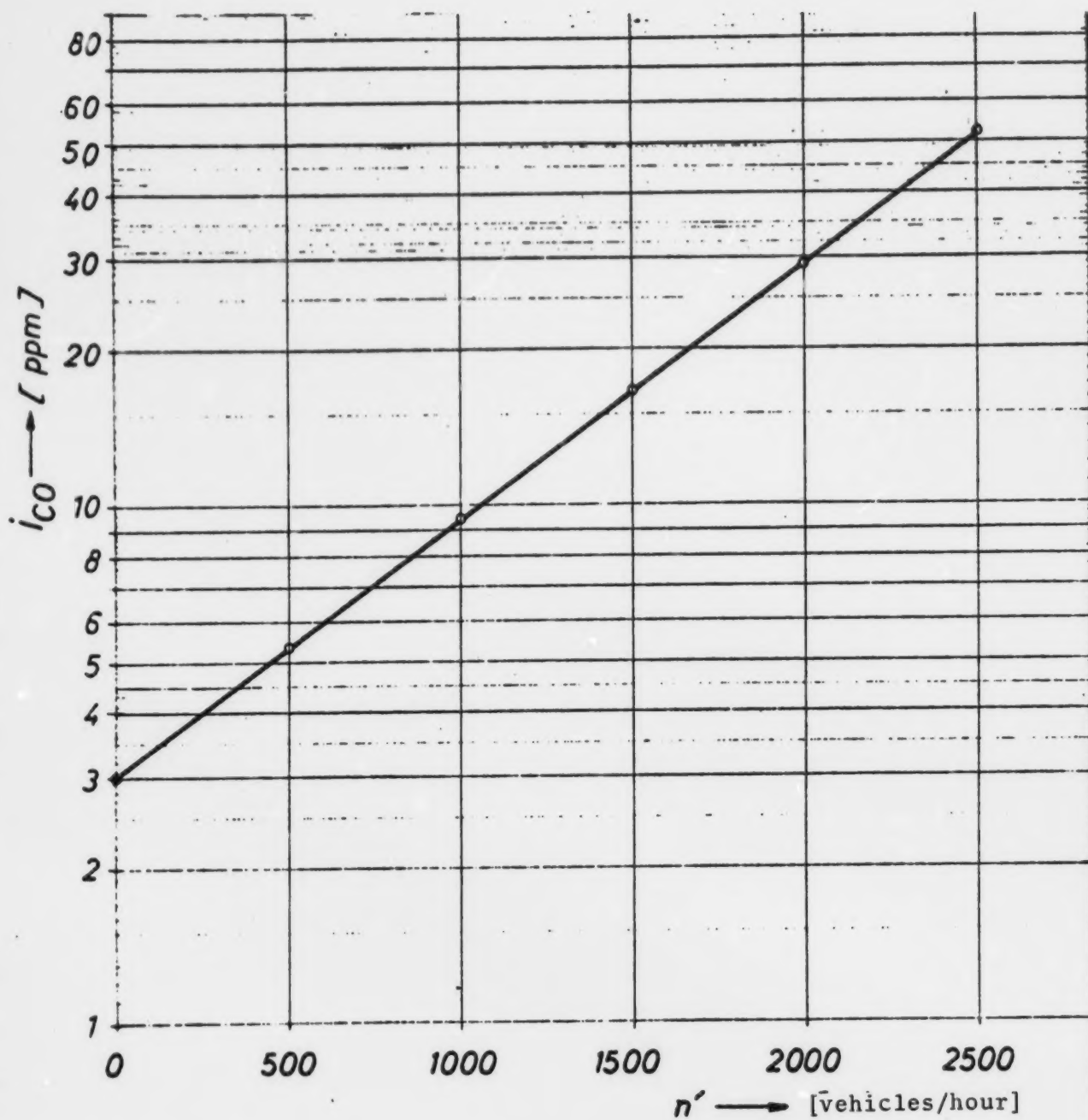
wind speed:  $0-\infty$  m/s

Figure 32 Dependence of CO concentration on traffic  
street model 2, wind in street direction



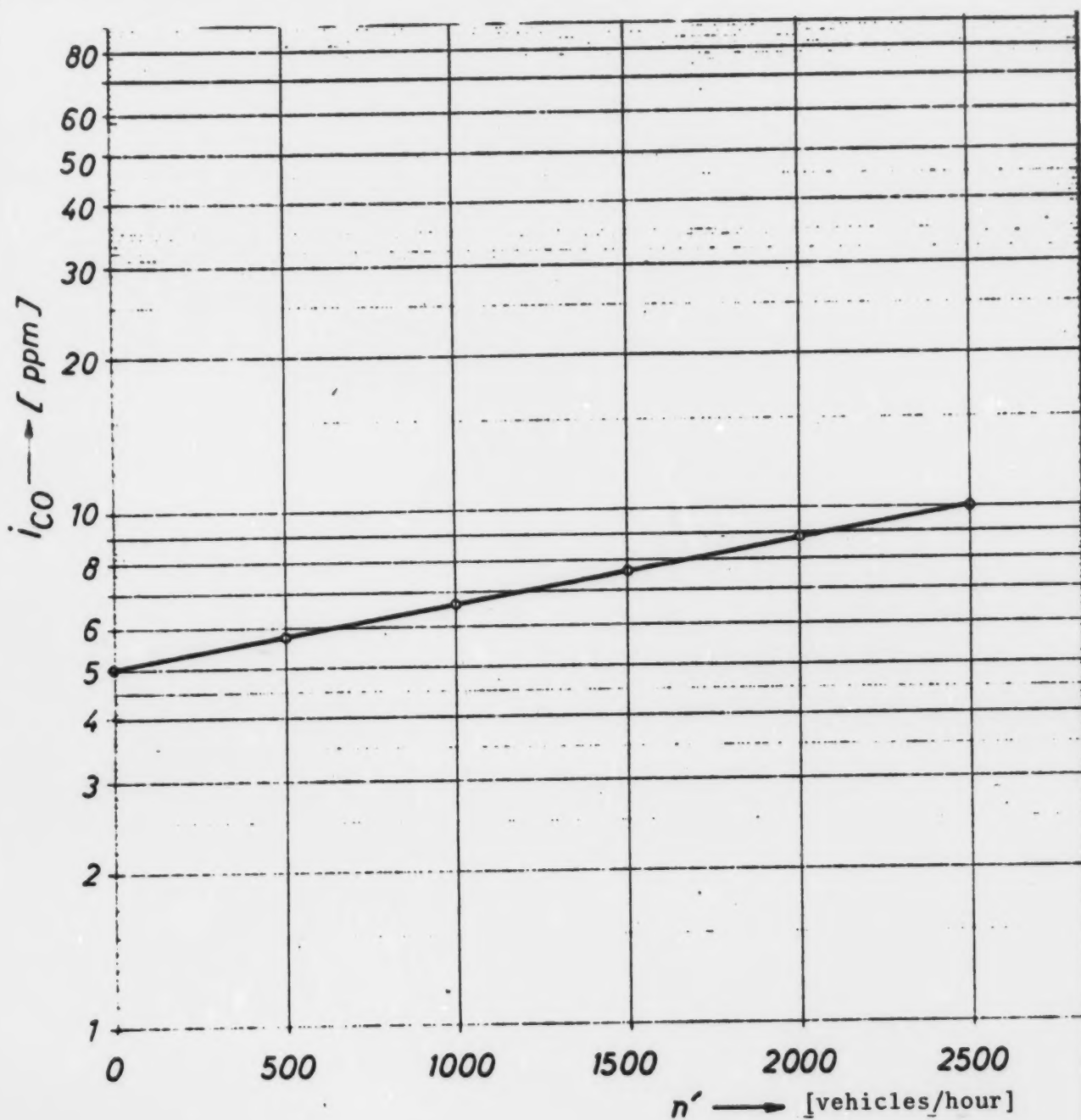
wind speed: **0 - 3 m/s**

**Figure 33** Dependence of CO concentration on traffic, street model 4, upwind



wind speed: **0 - 3 m/s**

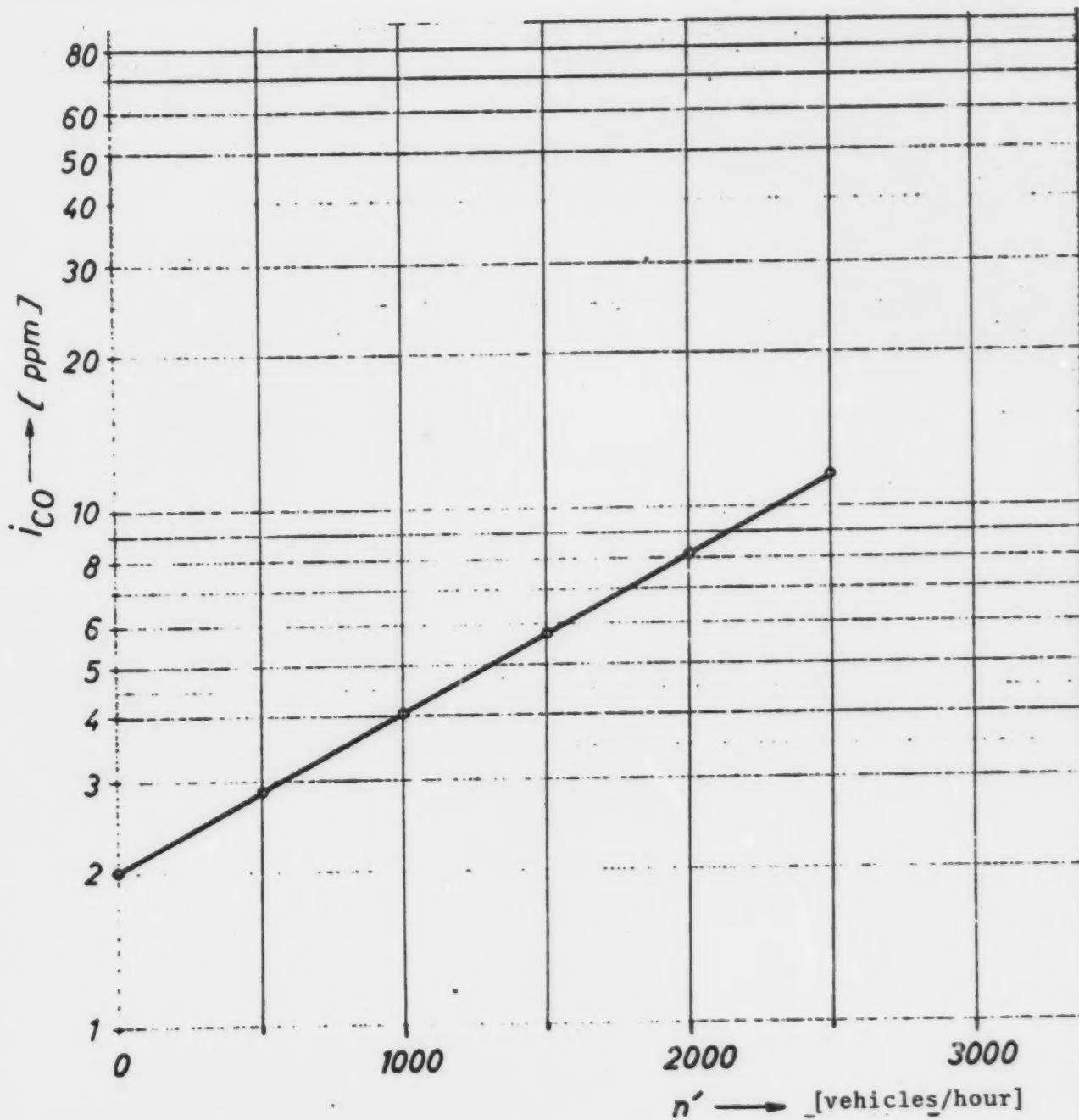
Figure 34 Dependence of CO concentration on traffic,  
street model 4, downwind



wind speed: 0-3 m/s

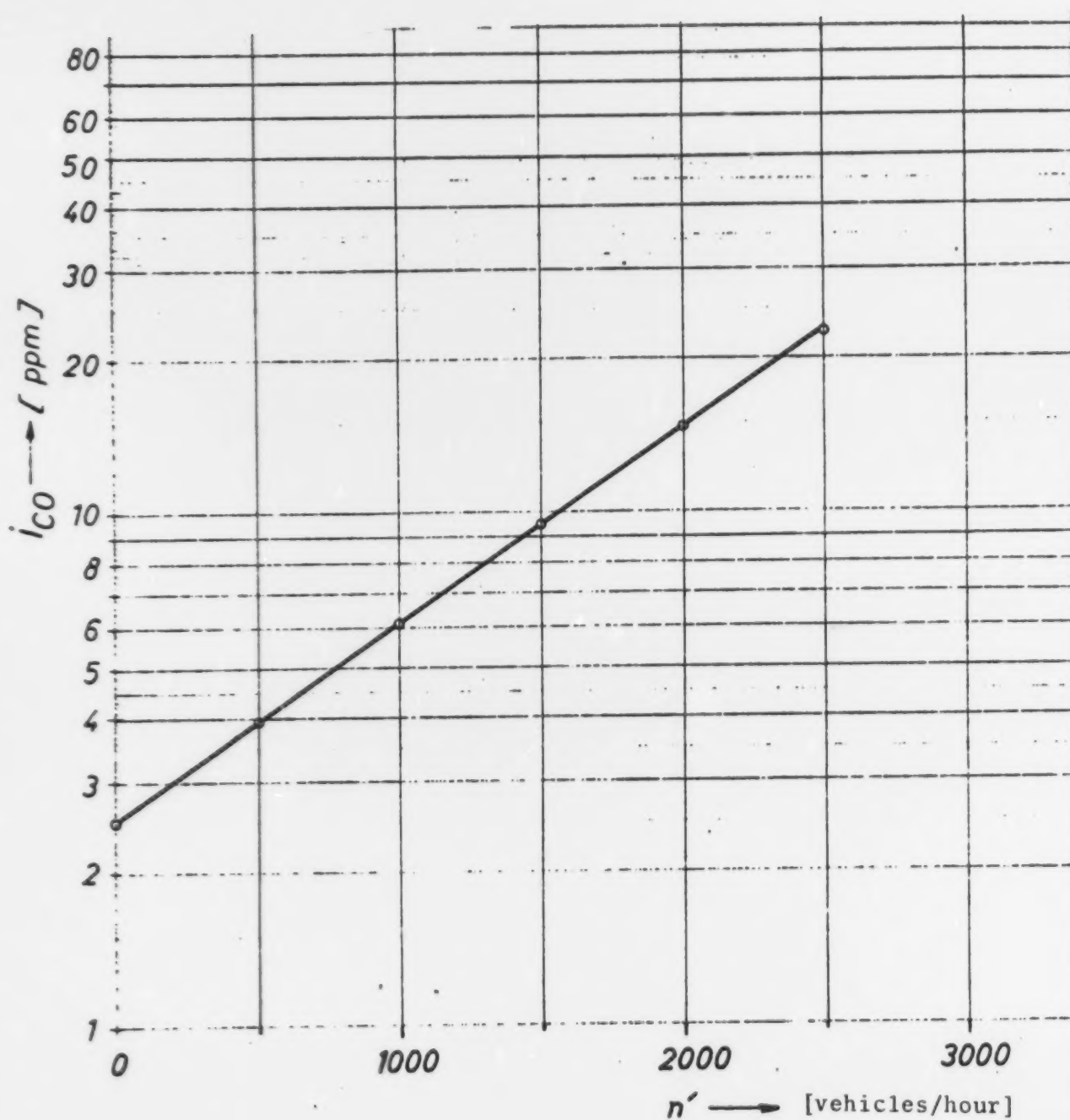
Figure 35 Dependence of CO concentration on traffic,  
street model 4, wind in street direction





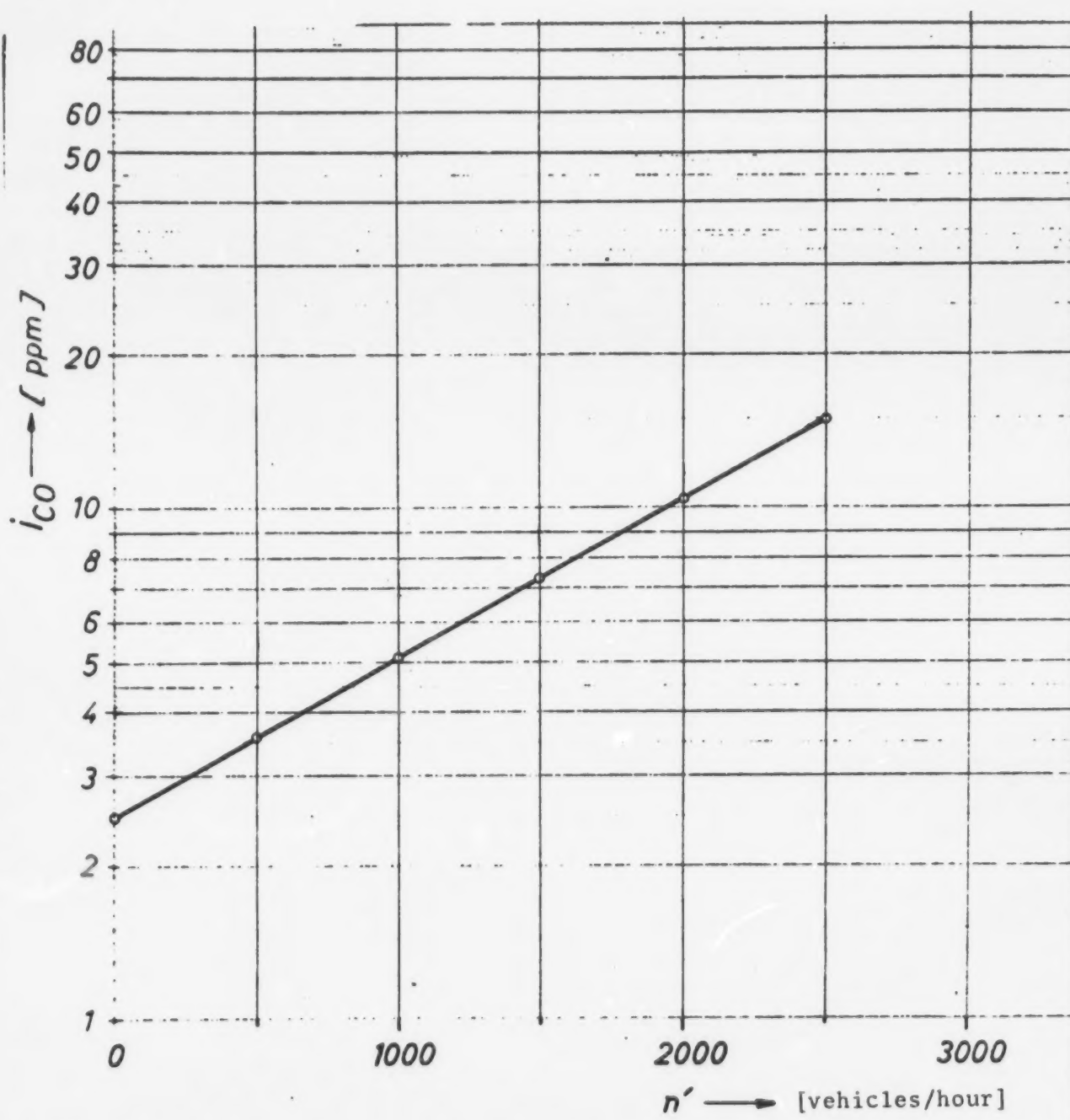
wind speed: 0 - 3 m/s

Figure 36 Dependence of CO concentration on traffic, street model 6, upwind



wind speed: 0 - 3 m/s

Figure 37 Dependence of CO concentration on traffic,  
street model 6, downwind



wind speed: 0 - 3 m/s

Figure 38 Dependence of CO concentration on traffic, street model 6, wind in street direction

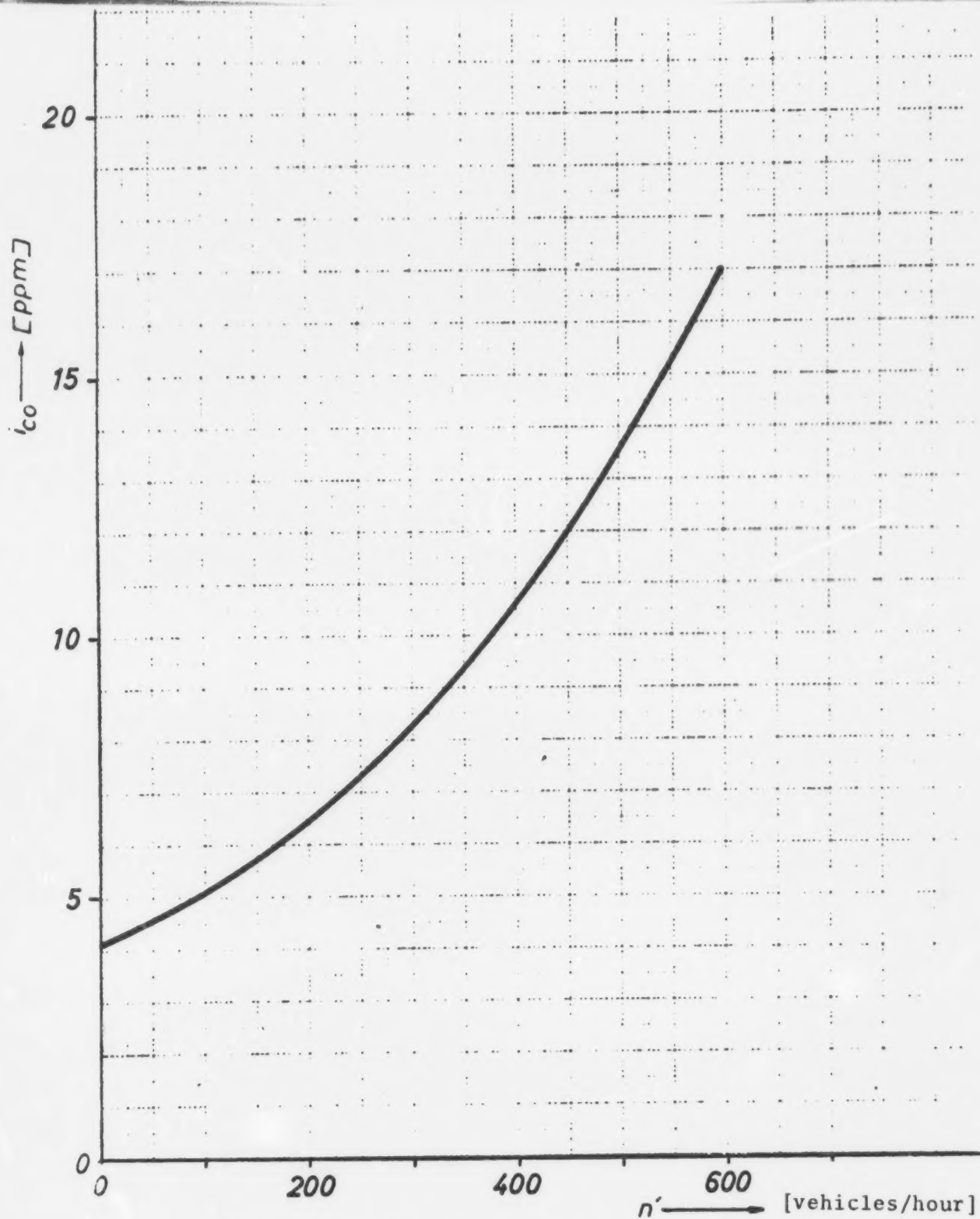


Figure 39 Dependence of the average CO concentration on traffic, street model 1



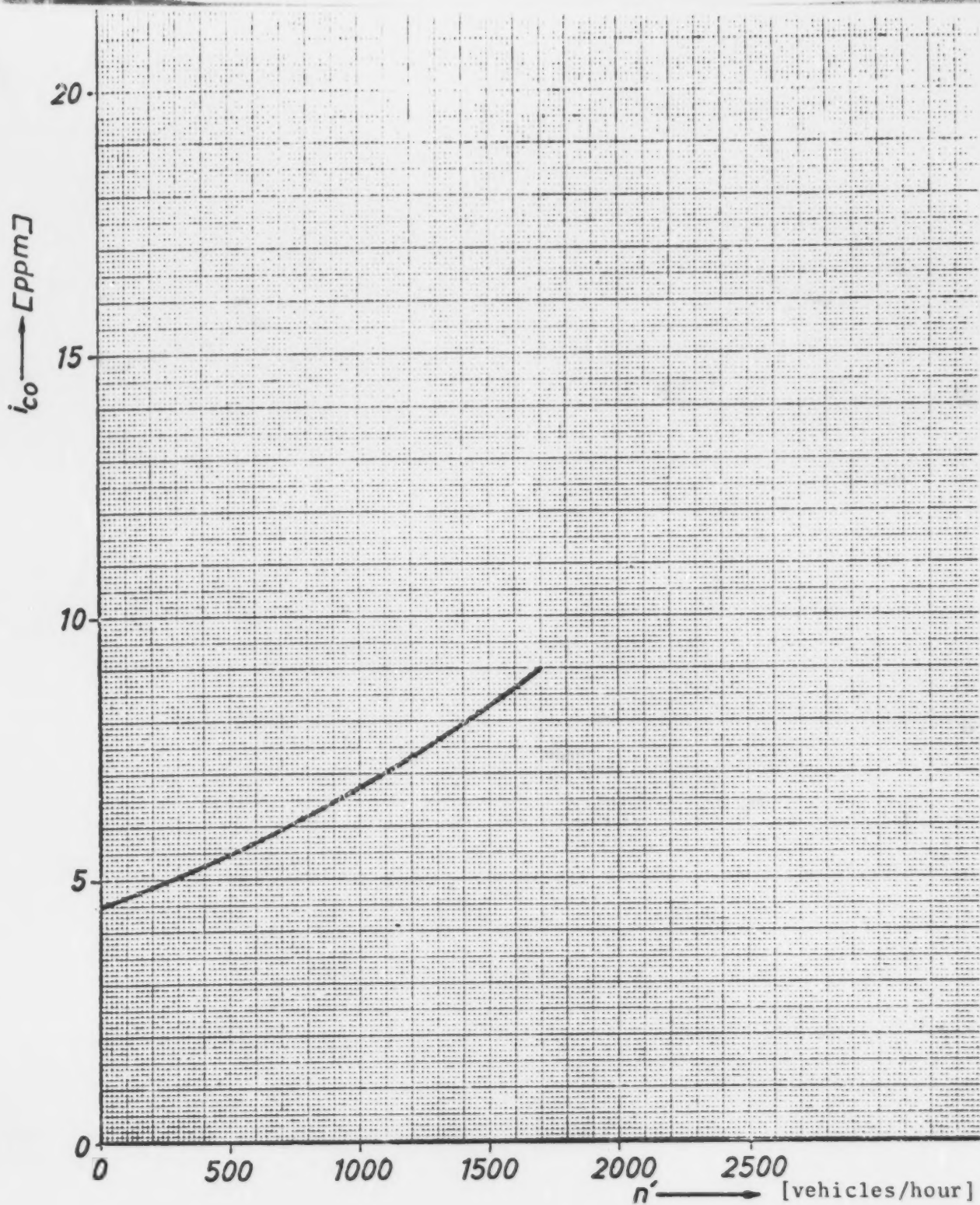


Figure 40 Dependence of the average CO concentration on traffic, street model 2



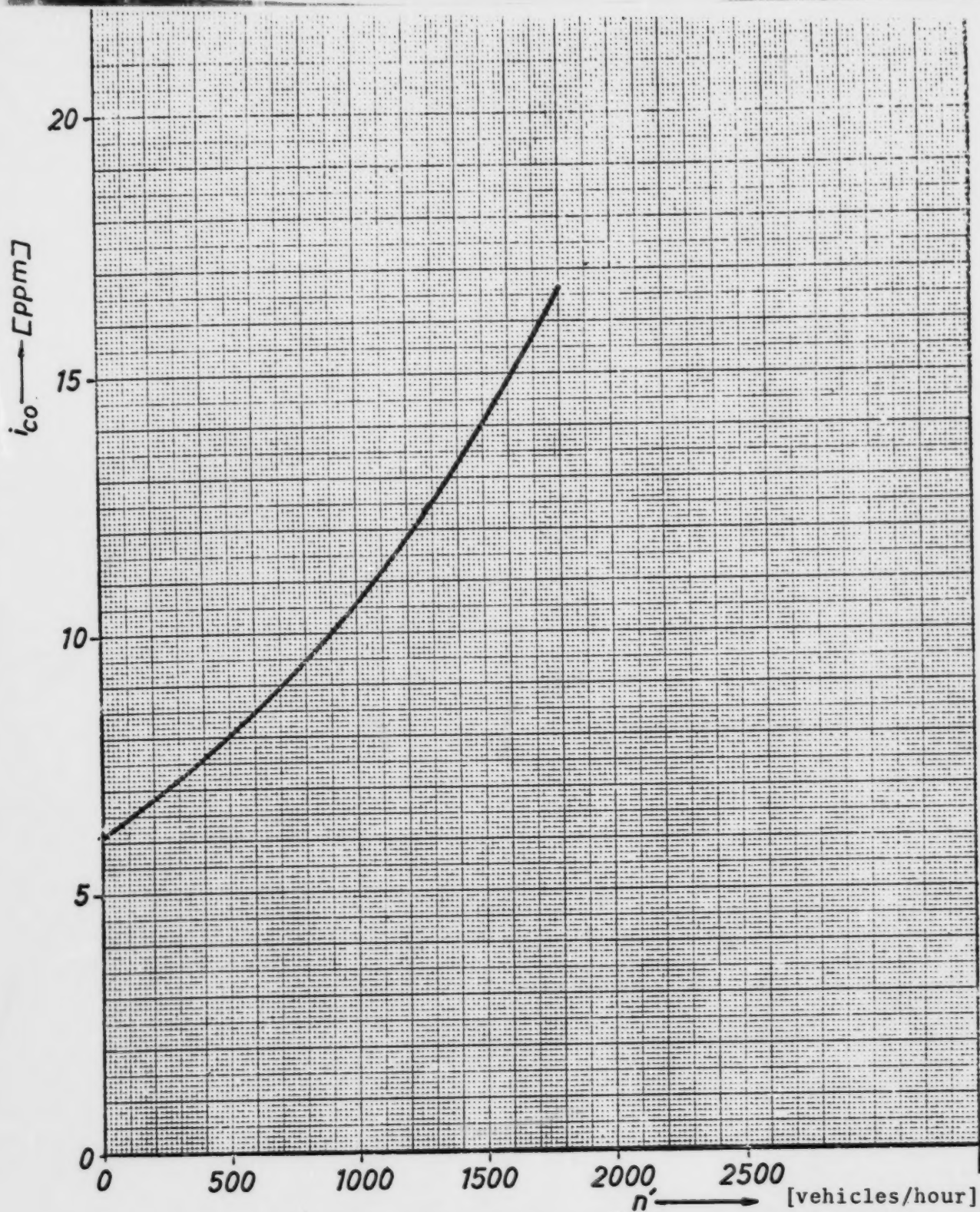


Figure 41 Dependence of the average CO concentration on traffic, street model 4

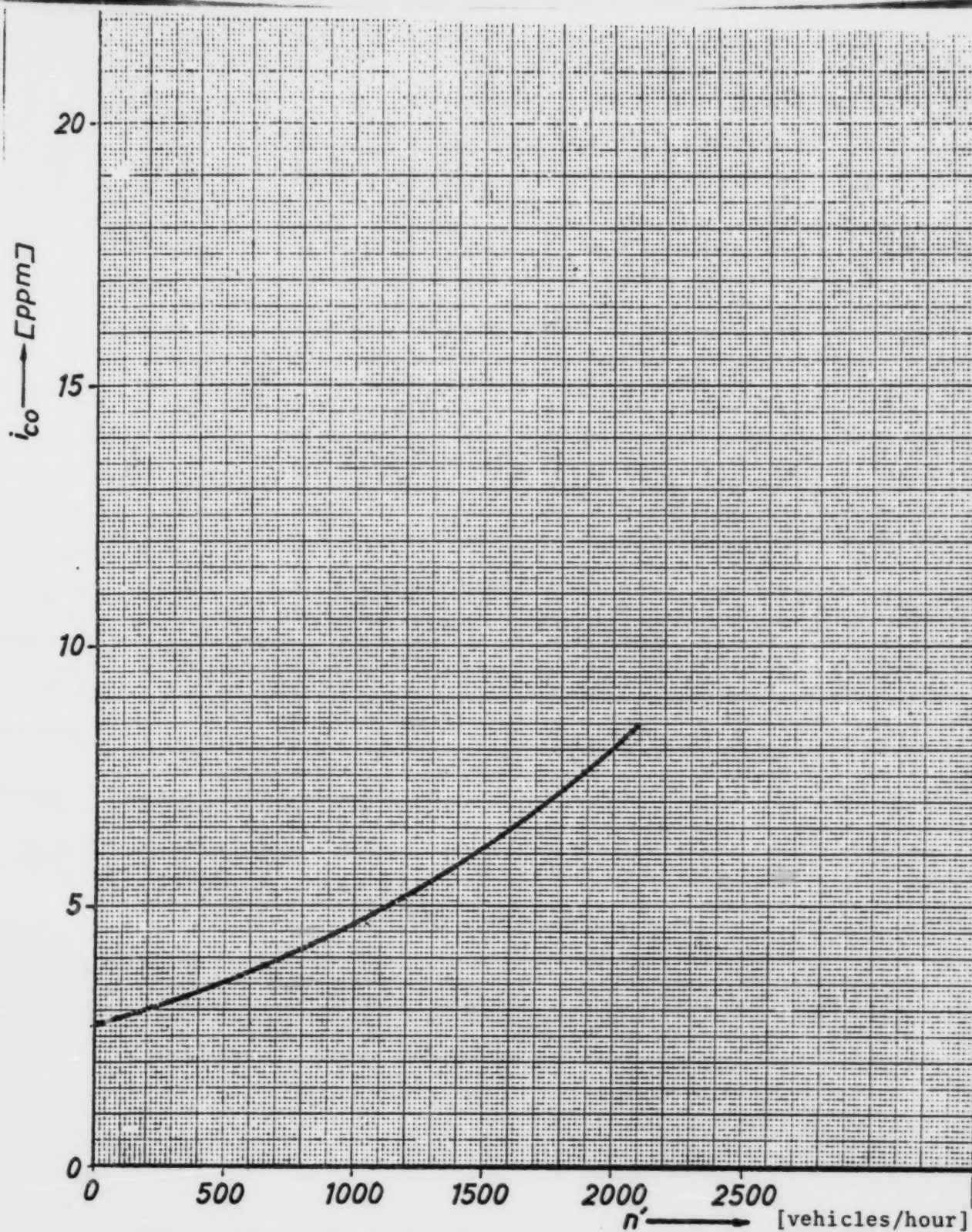


Figure 42 Dependence of the average CO concentration on traffic, street model 6



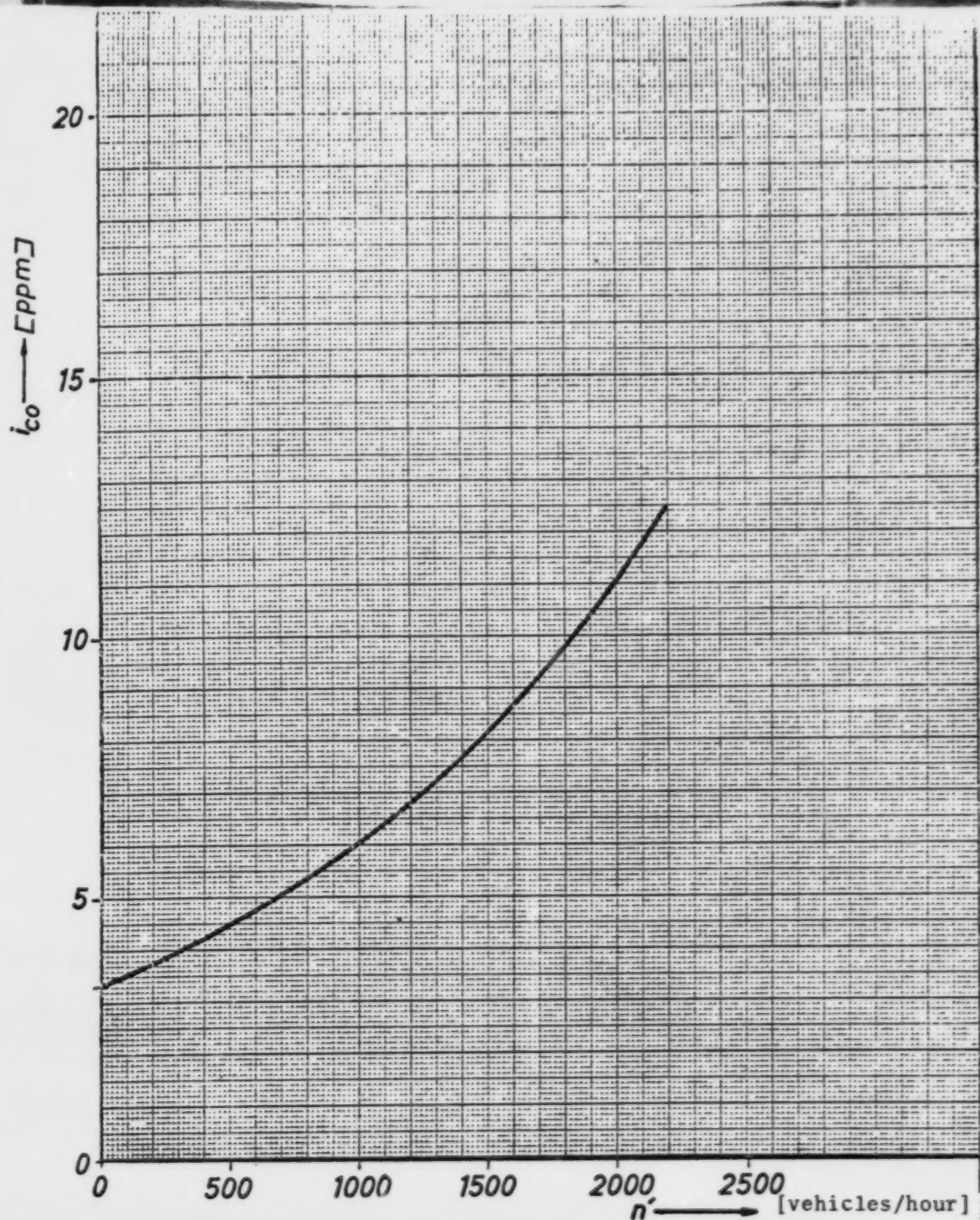
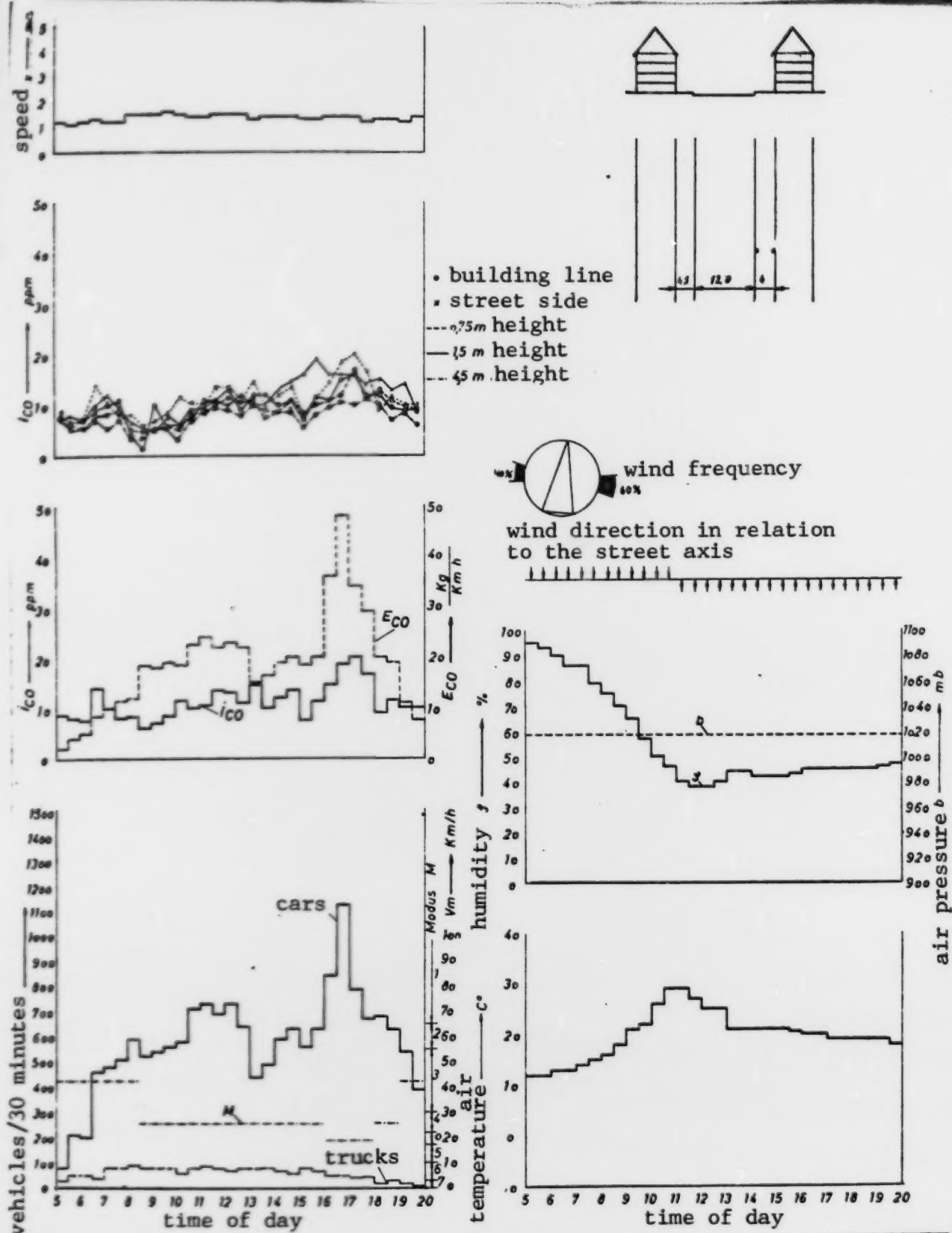
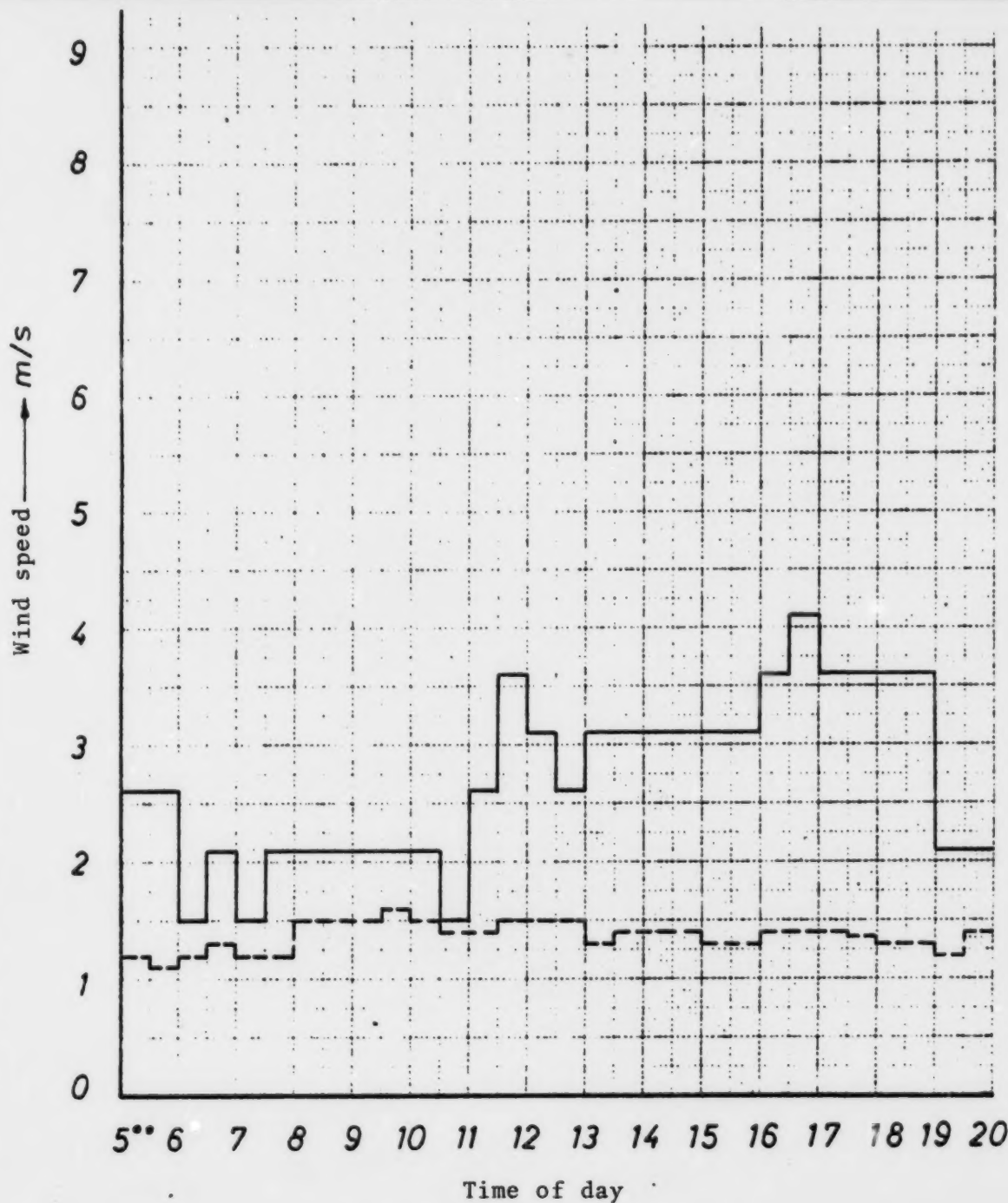


Figure 43 Dependence of the average CO concentration on traffic, street model 10



Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentrat. .. at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 1  
Date: July, 1971



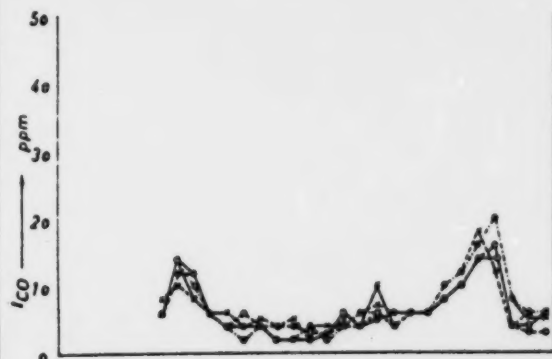
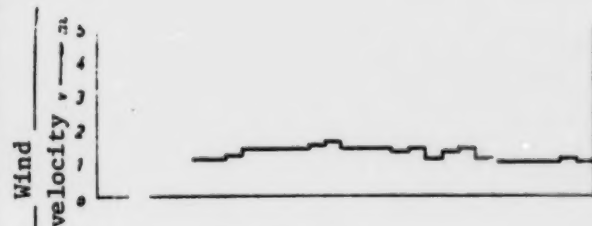
— Global wind speed  
 ---- Local wind speed

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 Rheinland

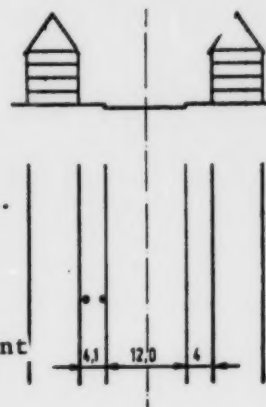
Daily lines for the course of the global  
 and local wind speed

Immissions,  
 city of Cologne  
 Measuring site: 1  
 Date: July, 1971





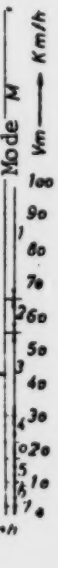
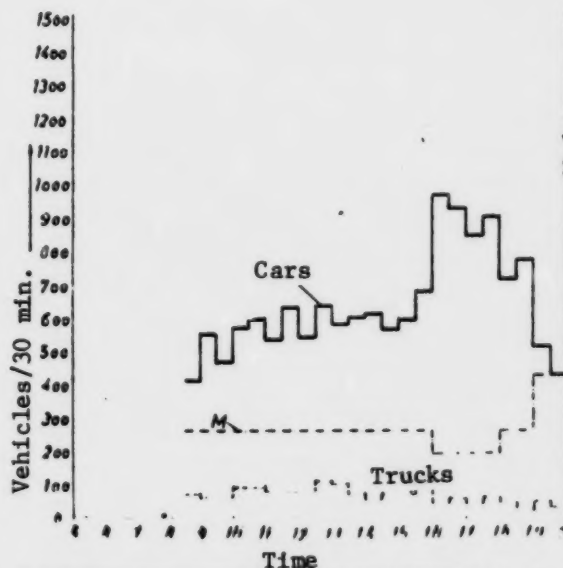
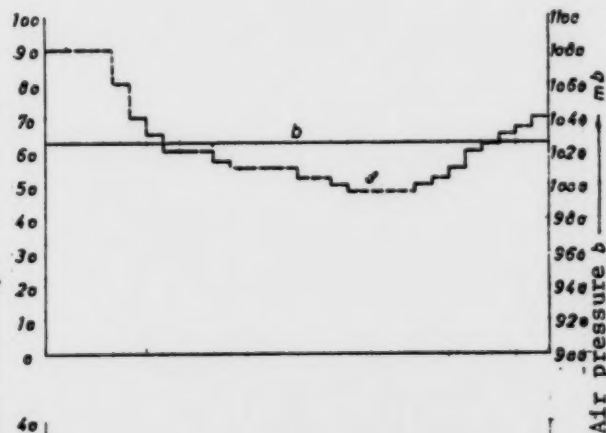
- Building alignment
- Street side
- 4.5 m Height
- 15 m Height
- - - 45 m Height



Wind frequency



Wind direction relative to street axis

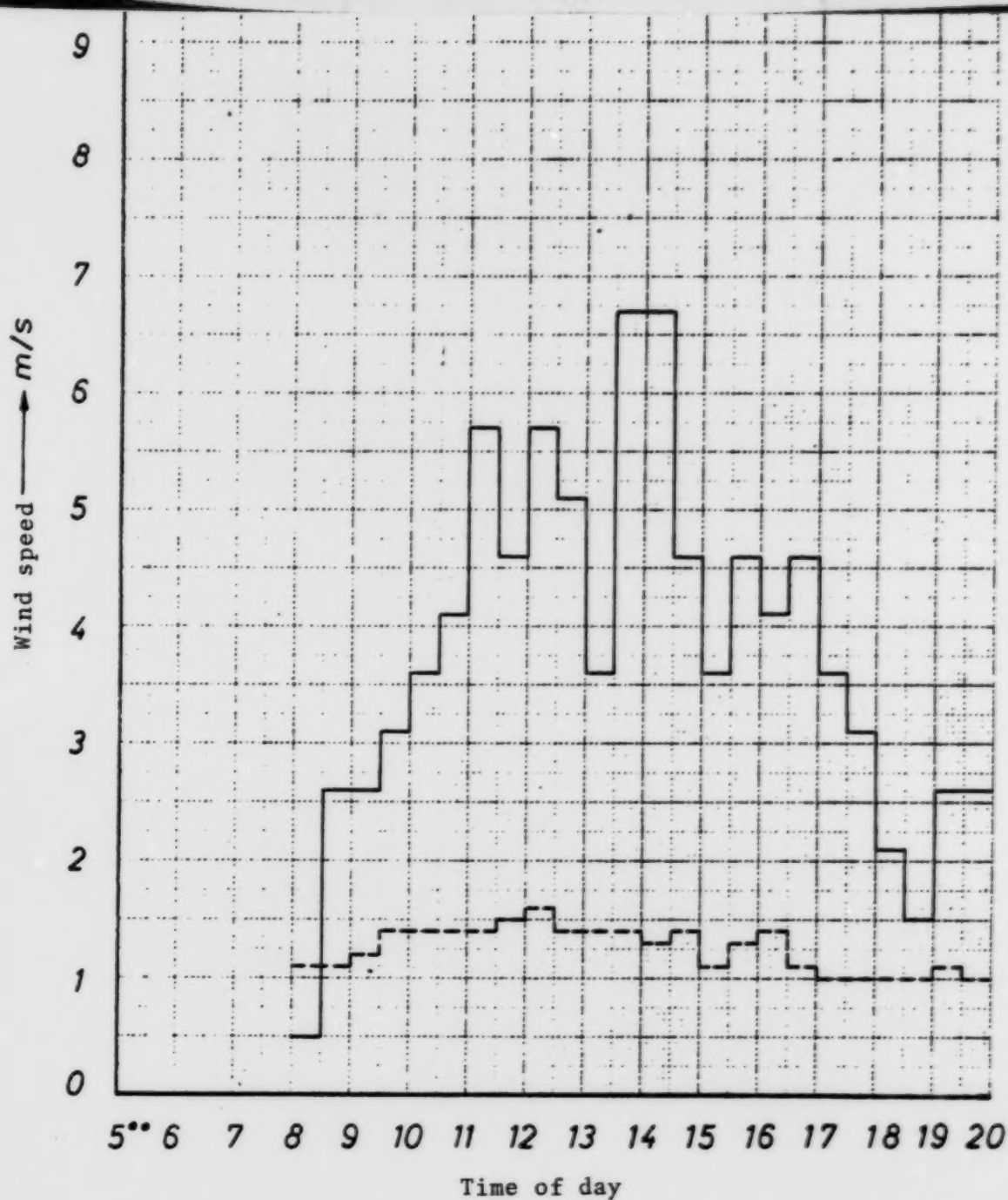


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Heimund

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

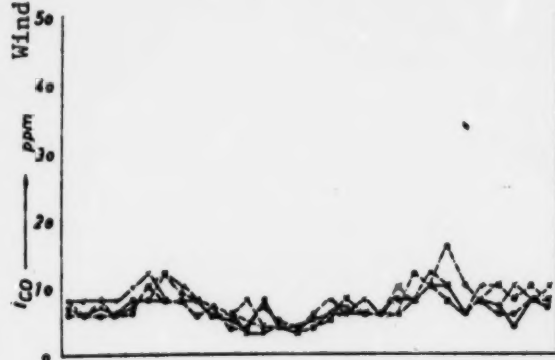
Immissions,  
city of Cologne  
Measuring site: 1  
Date: Oct. 28, 1971



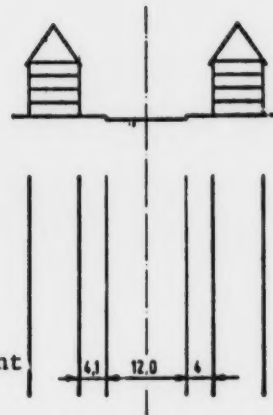
TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

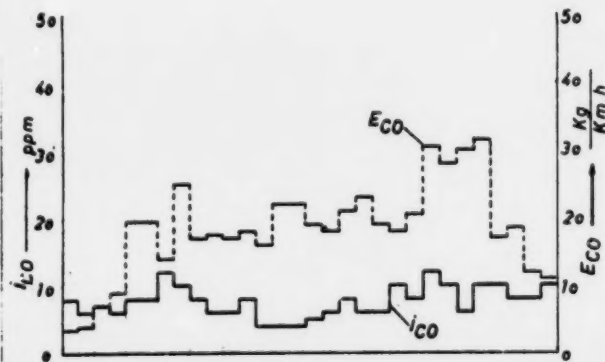
Emissions,  
city of Cologne  
Measuring site: 1  
Date: Oct. 28, 1971



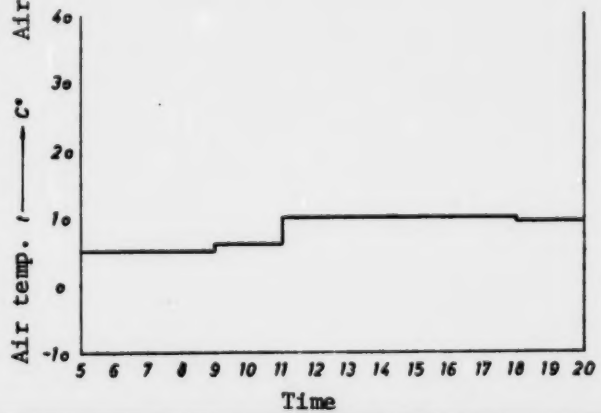
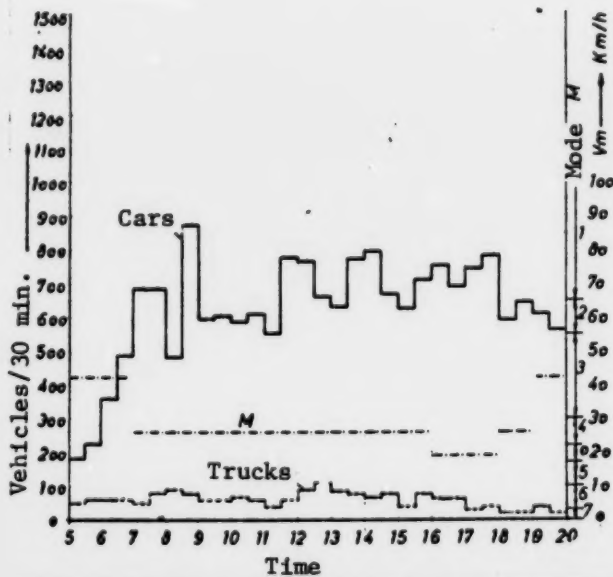
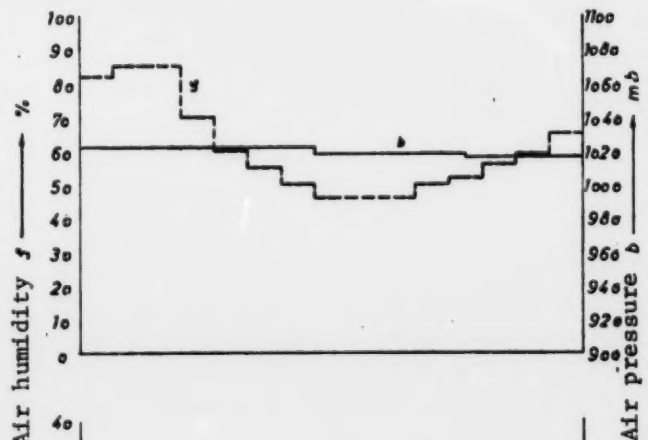
- Building alignment
- Street side
- 75 m Height
- 15 m Height
- - - 45 m Height



Wind frequency



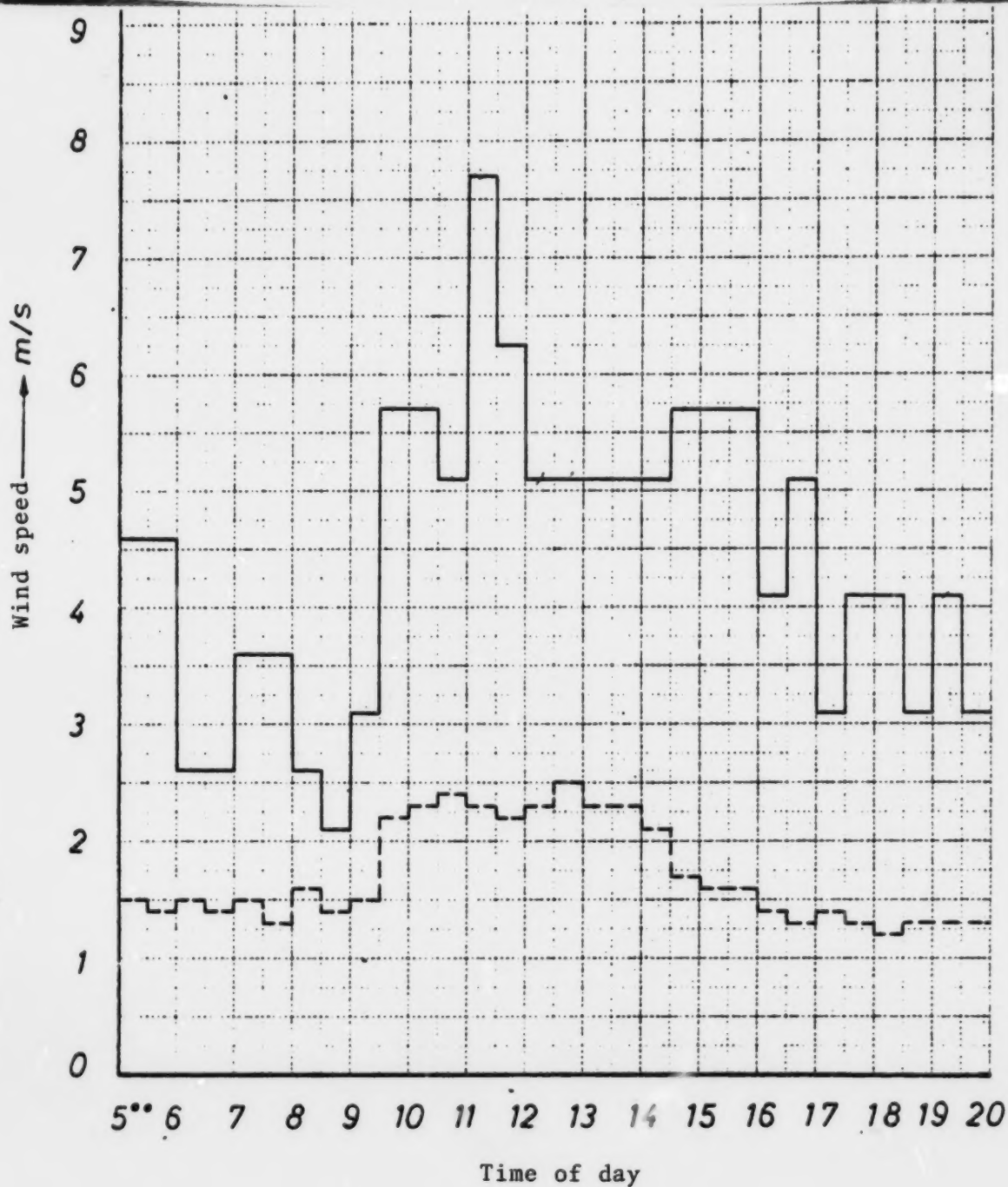
Wind direction relative to street axis



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Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 1  
Date: Oct. 29, 1971



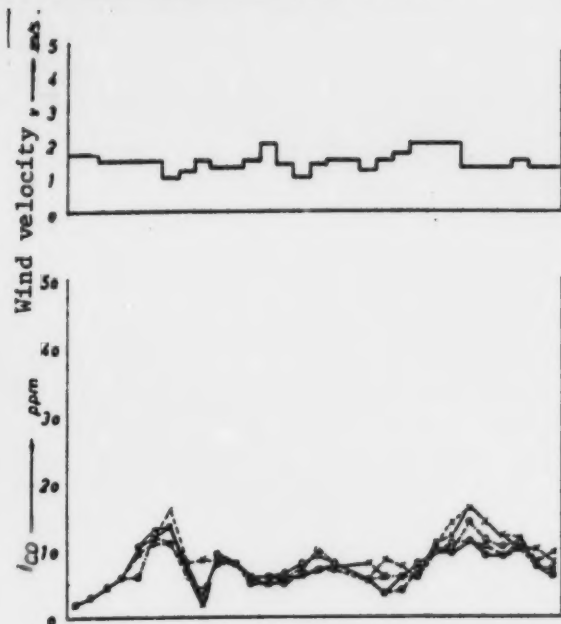
— Global wind speed  
 ---- Local wind speed

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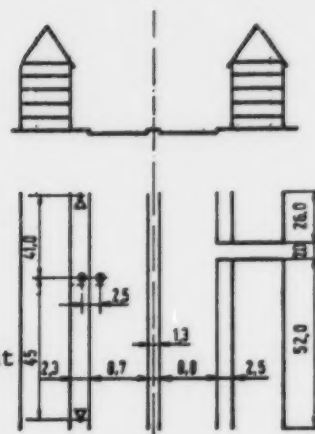
Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 1  
 Date: Oct. 29, 1971



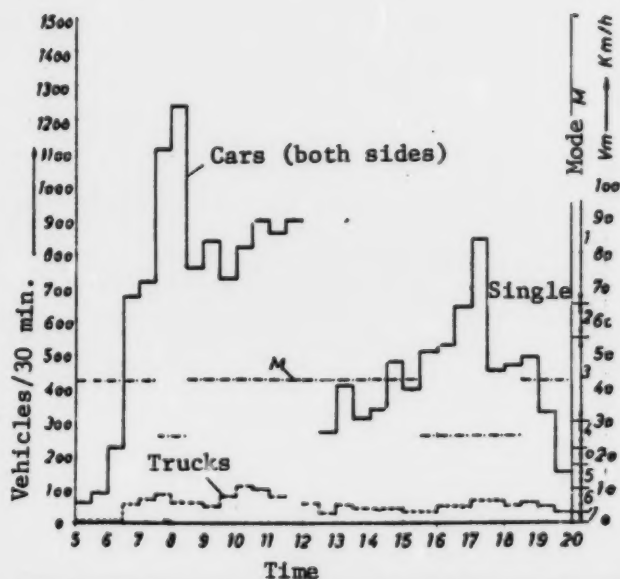
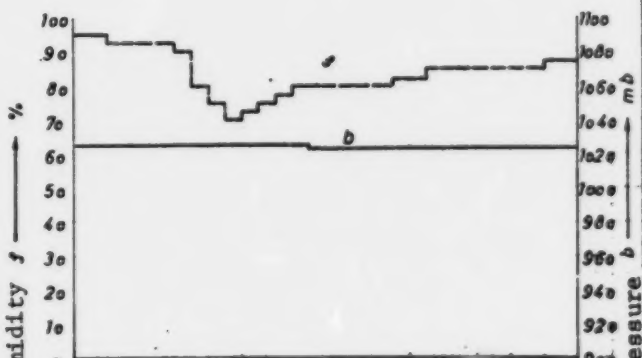
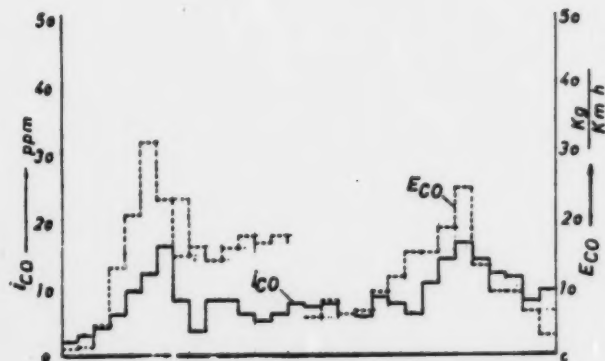
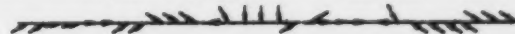


• Building alignment  
 \* Street side  
 --- 0.75 m Height  
 — 15 m Height  
 - - - 45 m Height



Wind frequency

Wind direction relative to street axis



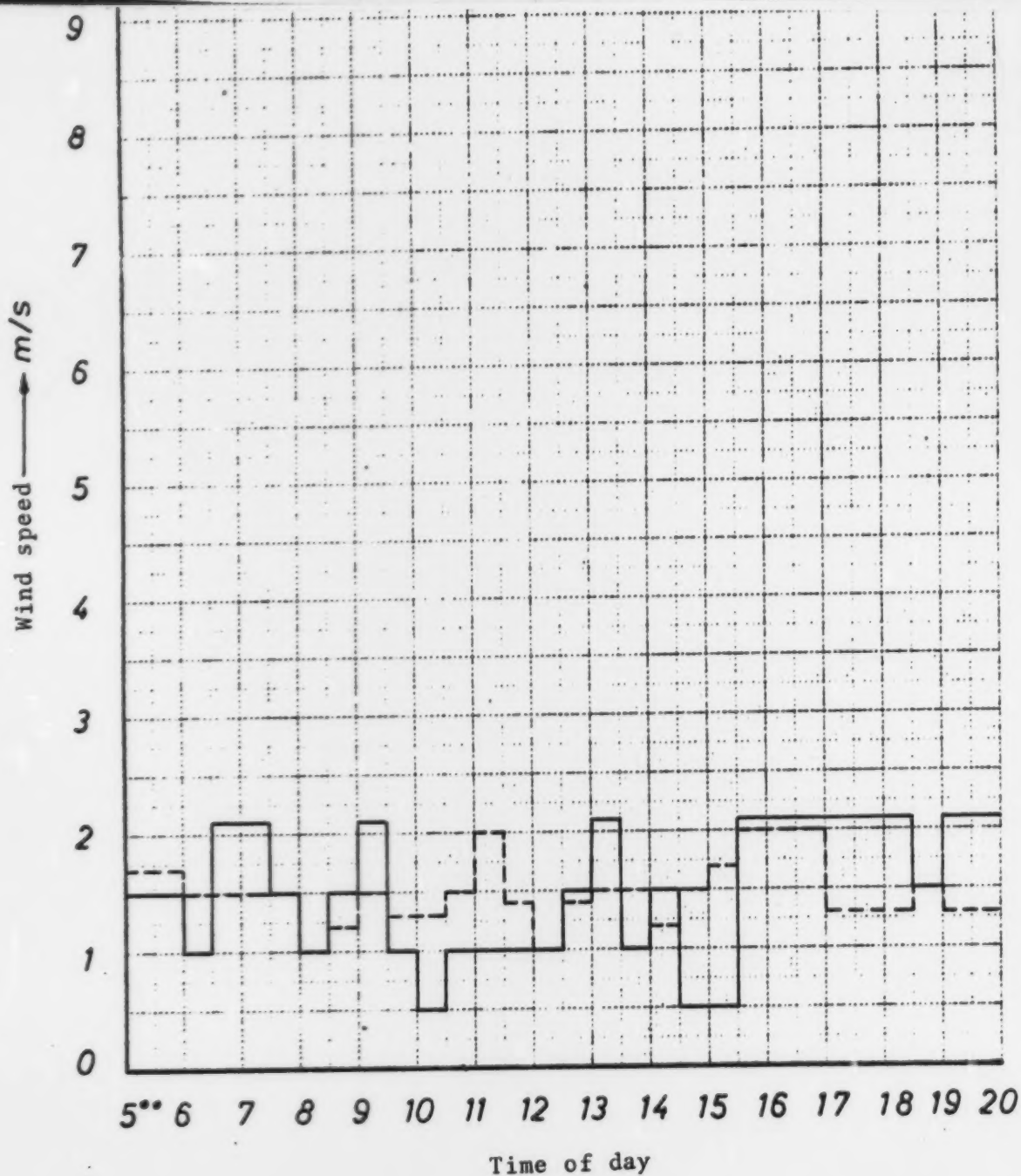
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Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions, city of Cologne  
 Measuring site.

Date: Nov. 2, 1971



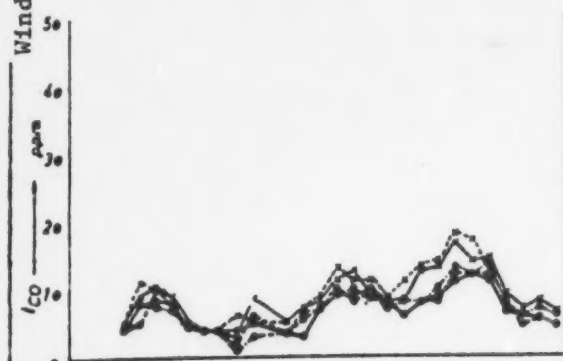
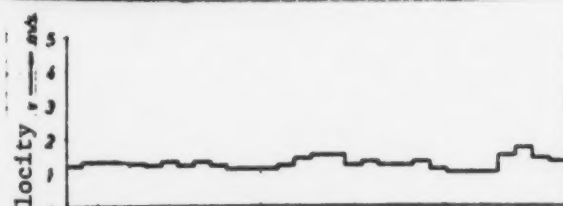
— Global wind speed

---- Local wind speed

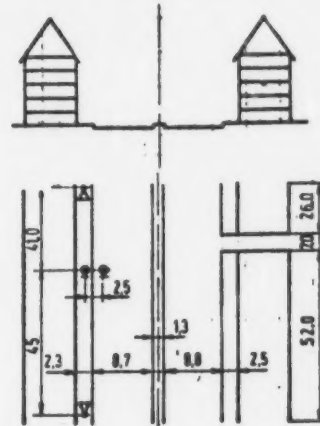
TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 2  
Date: Nov. 2, 1971

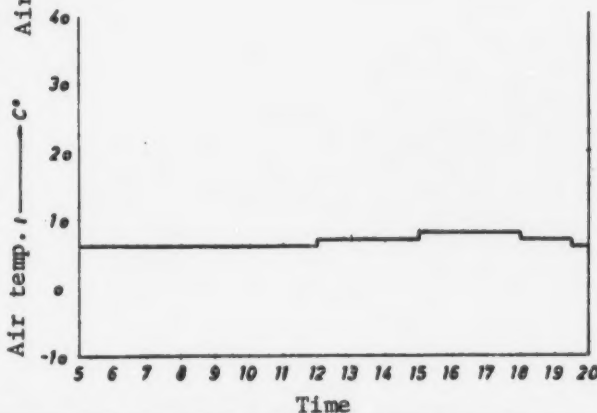
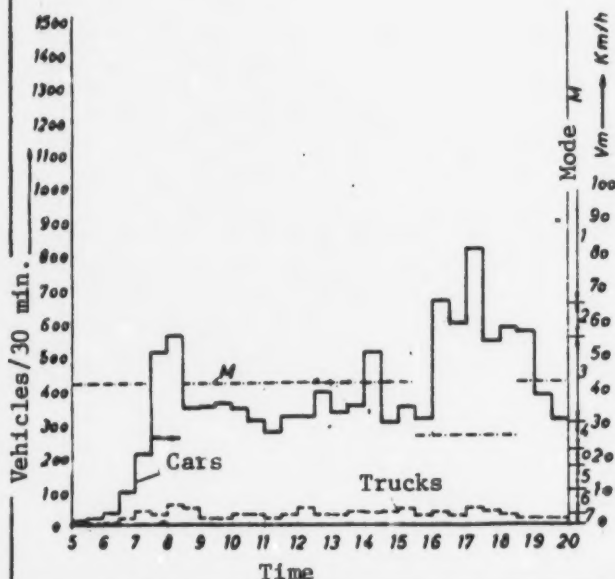
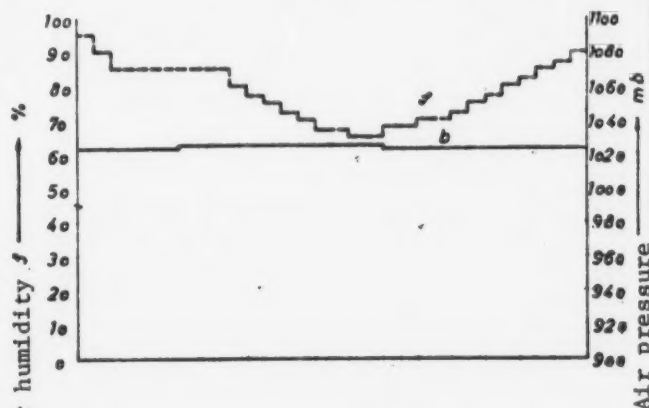
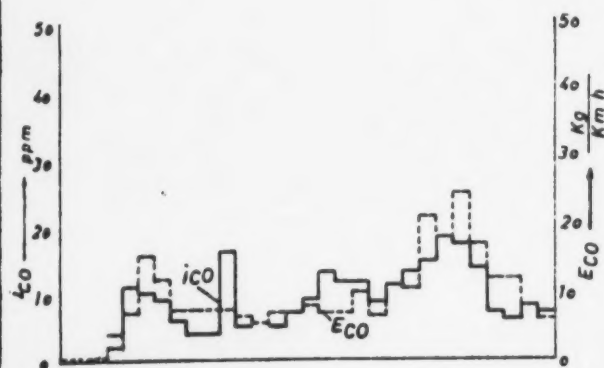


Building  
 • alignment  
 • Street side  
 --- 75m Height  
 — 15m Height  
 --- 45m Height



Wind frequency

Wind direction relative to street axis

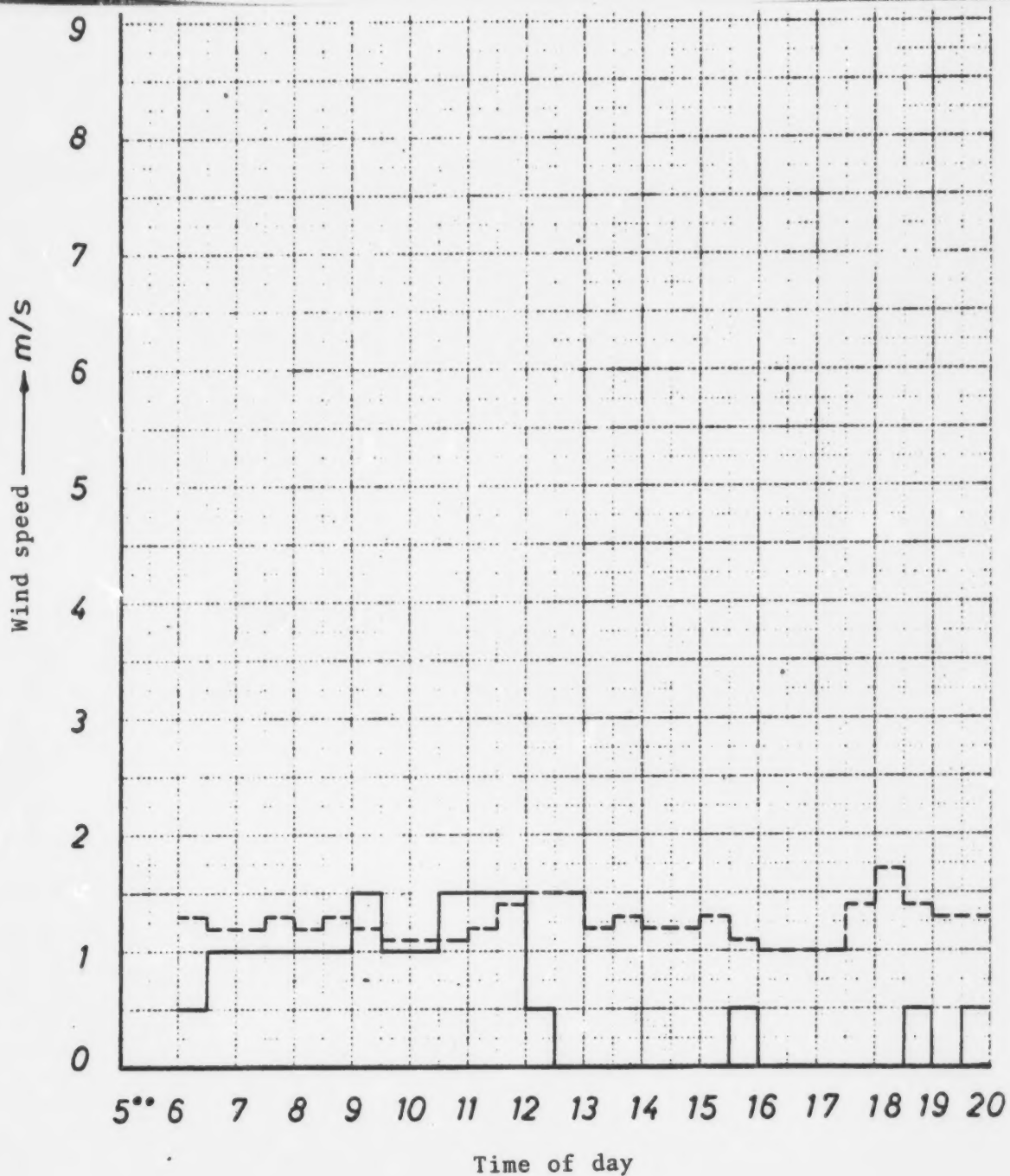


TÜV

Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
 city of Cologne  
 Measuring site: 2  
 — Date: Nov. 3, 1971

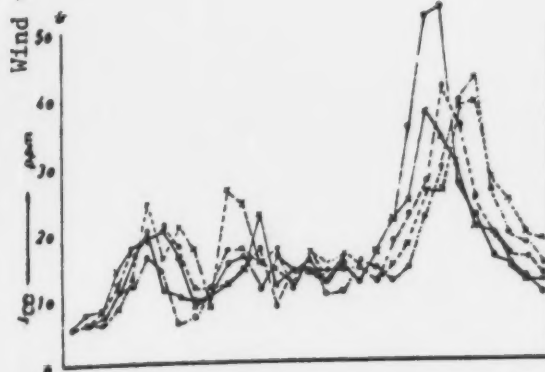


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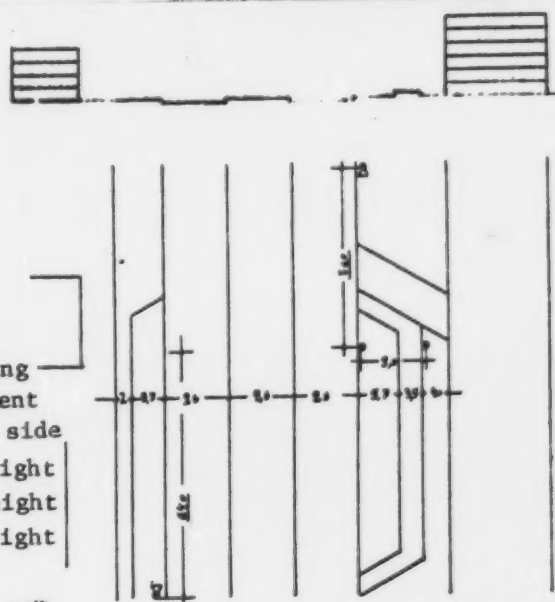
Daily lines for the course of the global and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 2  
Date: Nov. 3, 1971



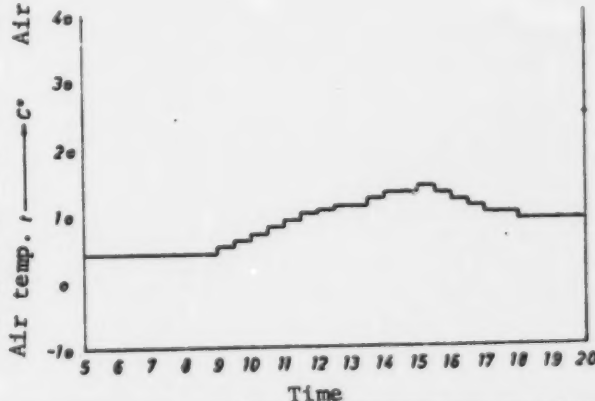
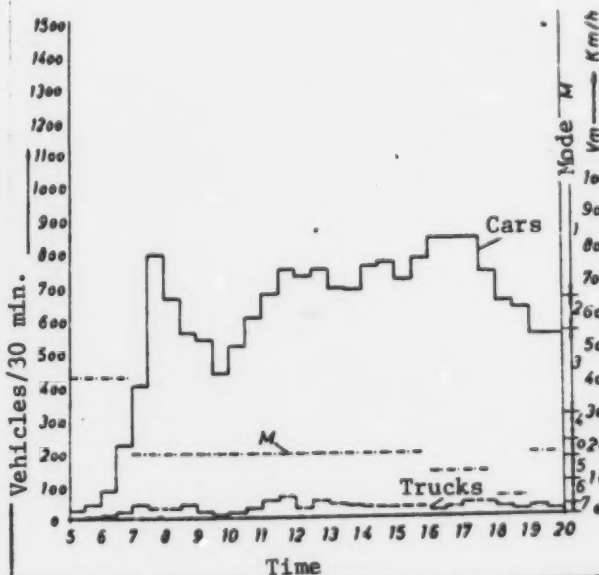
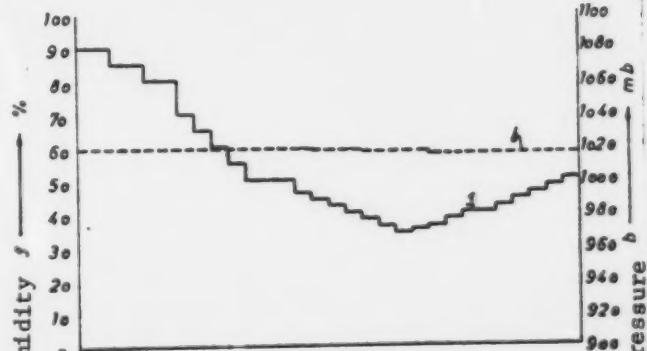
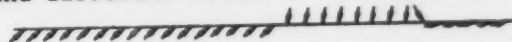


Building  
 • alignment  
 • Street side  
 --- 0.75 m Height  
 --- 1.5 m Height  
 --- 4.5 m Height



Wind frequency

Wind direction relative to street axis



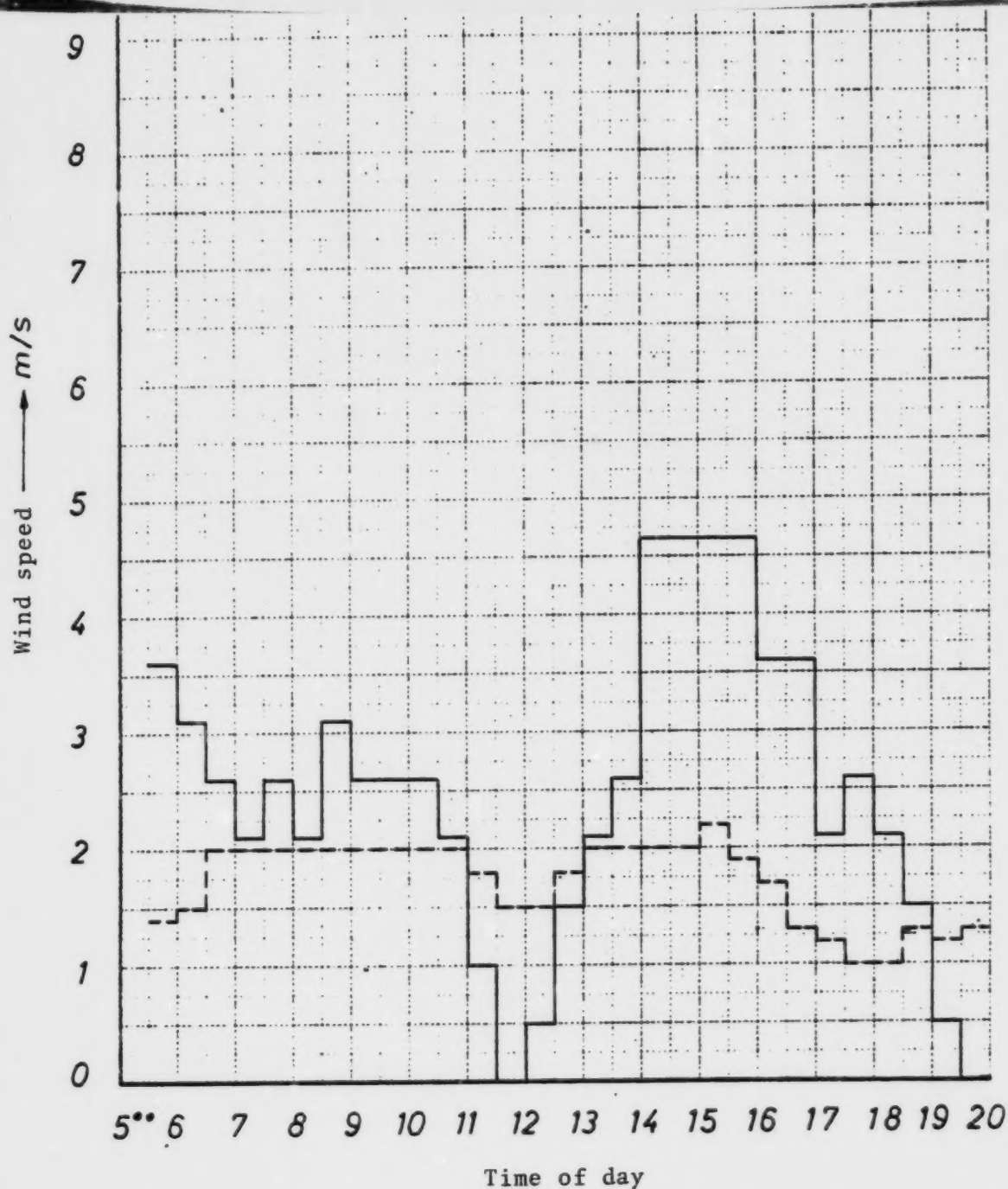
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Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions, city of Cologne  
 Measuring site: 3

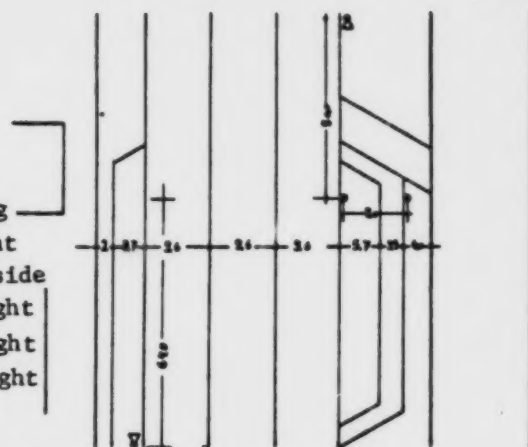
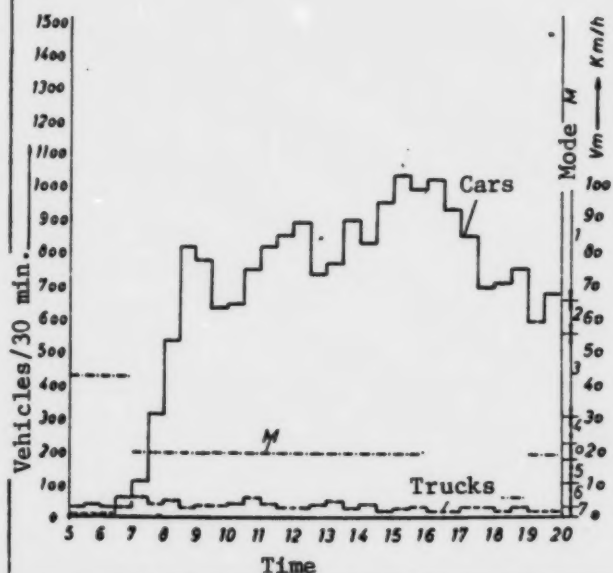
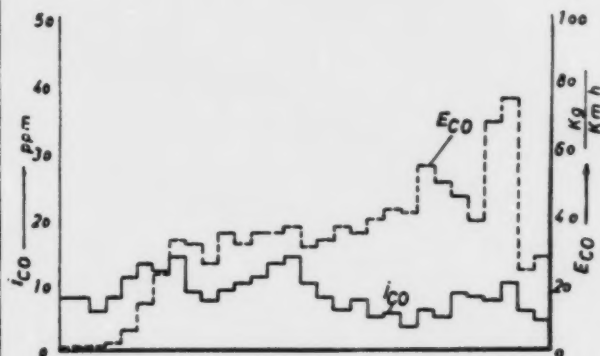
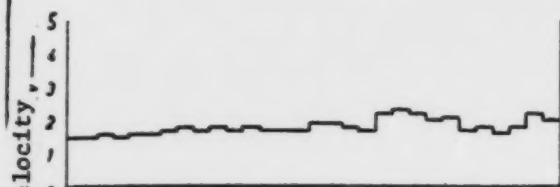
- Date: Nov. 4, 1971



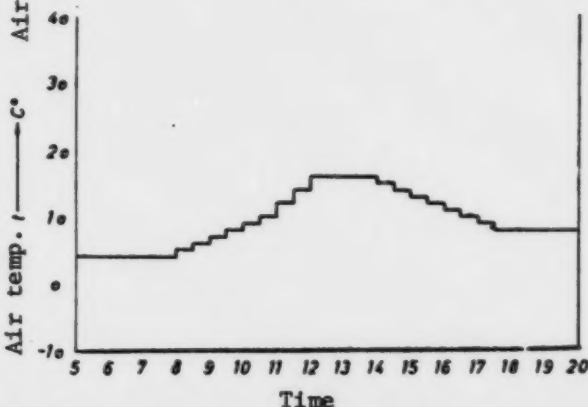
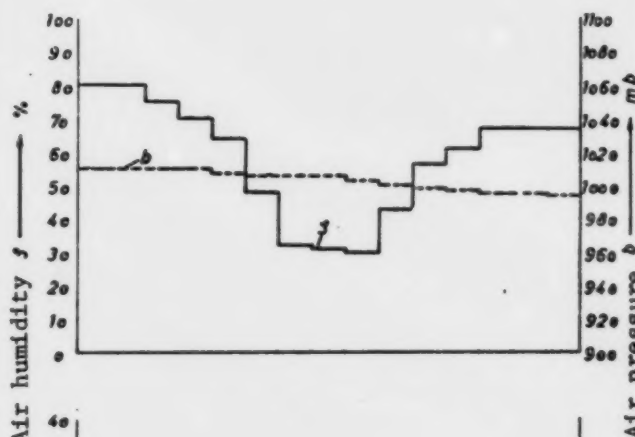
TÜV  
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Daily lines for the course of the global  
and local wind speed

Immissions,  
city of Cologne  
Measuring site: 3  
Date: Nov. 4, 1971



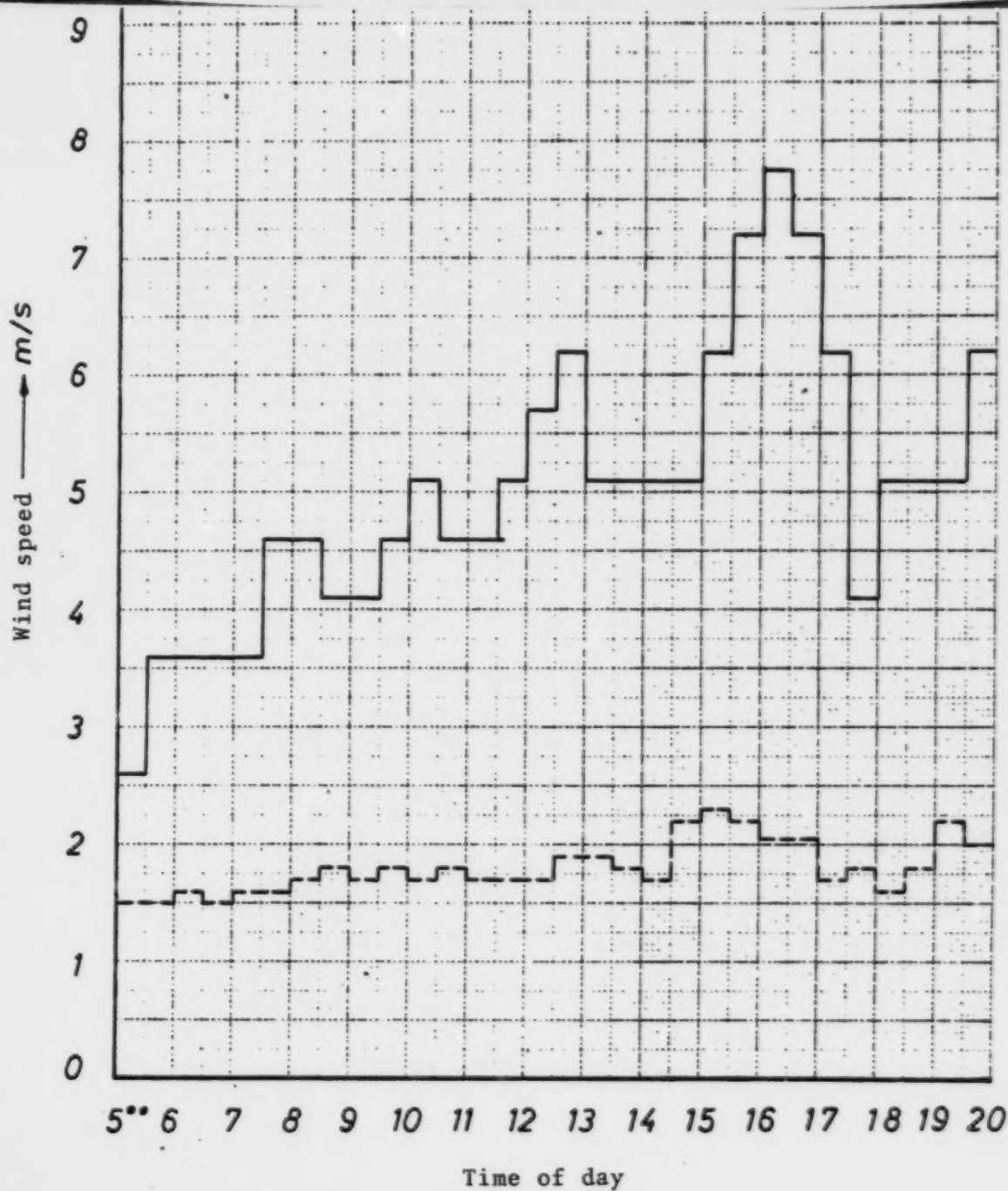
Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions, city of Cologne  
Measuring site: 3  
Date: Nov. 5, 1971



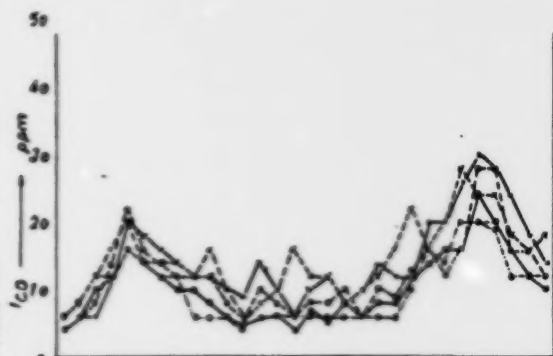
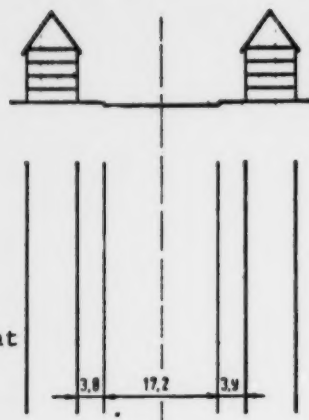
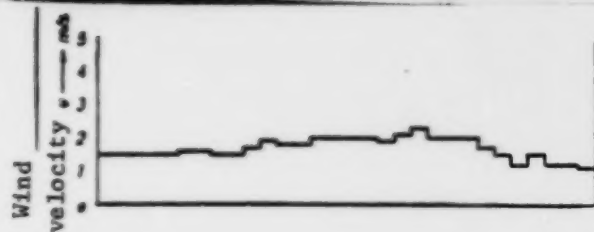
— Global wind speed  
 ---- Local wind speed

TÜV  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 3  
 Date: Nov. 5, 1971

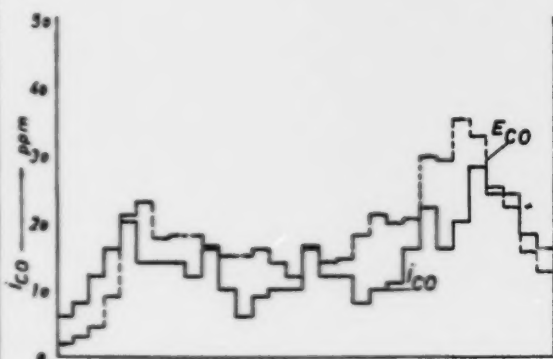




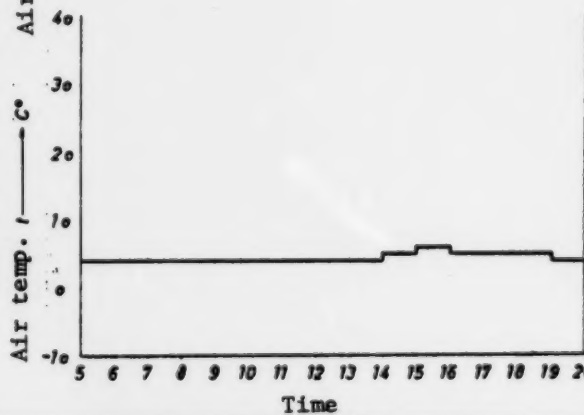
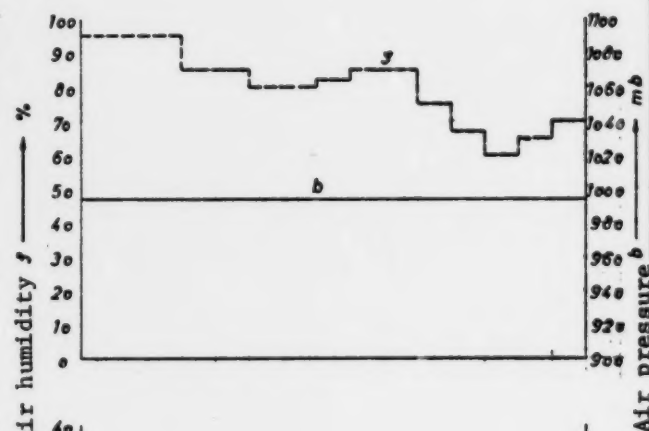
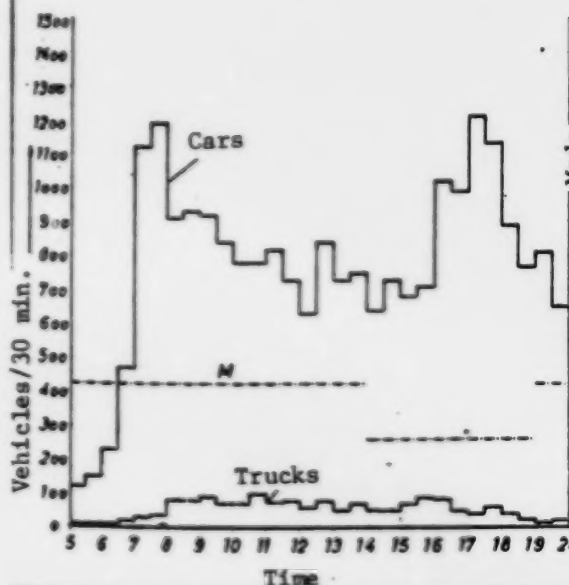
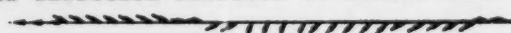
• Building alignment  
• Street side  
--- 75 m Height  
— 15 m Height  
--- 45 m Height



Wind frequency



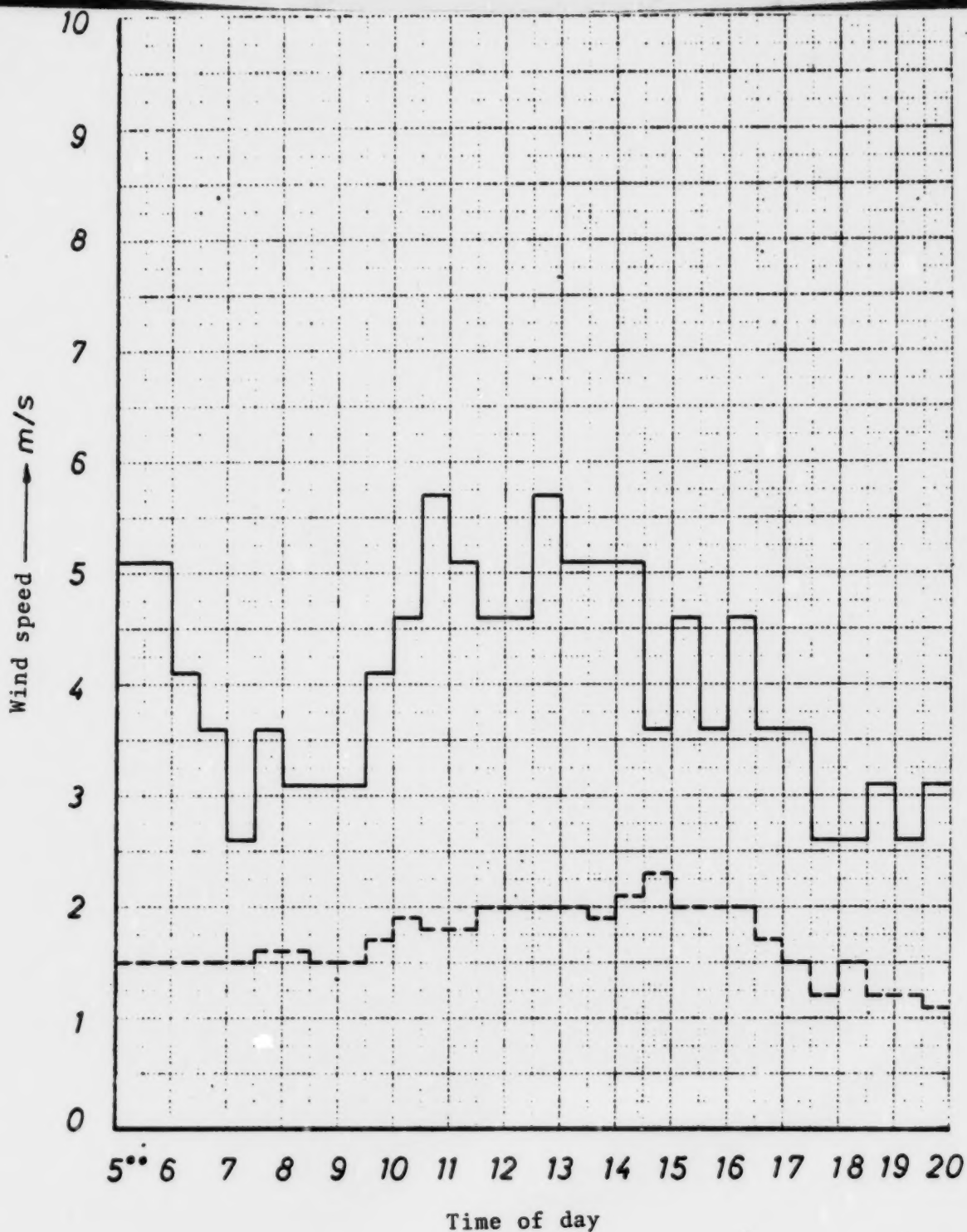
Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for the course of the exhaust gas component  $\text{CO}$  (immission, emission),  $\text{CO}$  concentration at various heights, traffic density and meteorological quantities.

Immissions, city of Cologne  
Measuring site: 4  
Date: Nov. 8, 1971

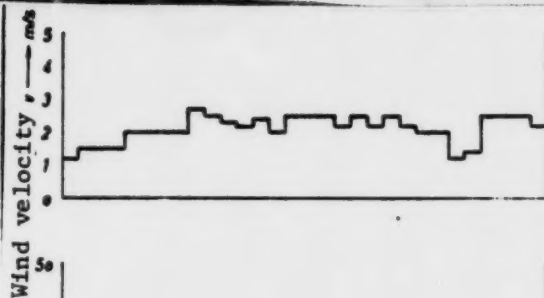


— Global wind speed  
 ---- Local wind speed

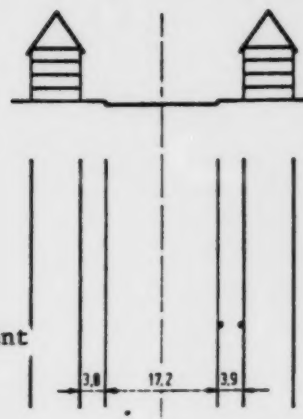
**TÜV**  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 4  
 Date: Nov. 8, 1971

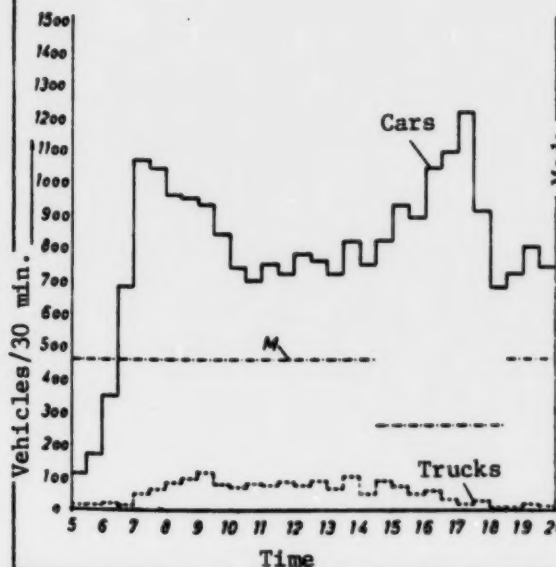
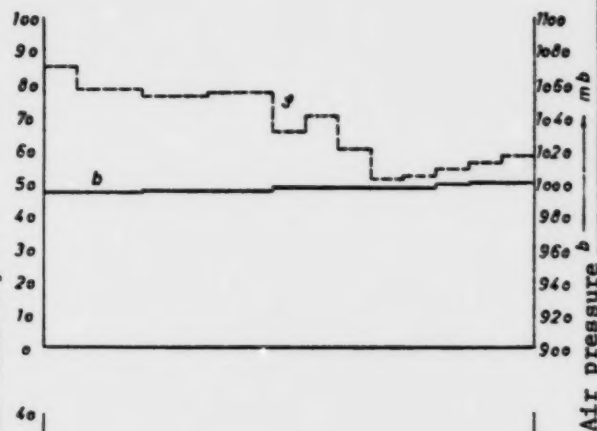
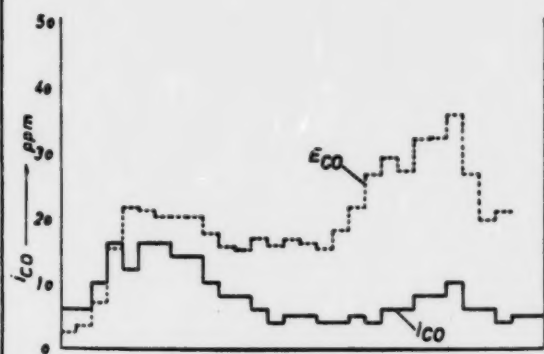
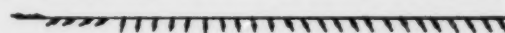


• Building alignment  
• Street side  
--- 0.75 m Height  
— 1.5 m Height  
--- 4.5 m Height



Wind frequency

Wind direction relative to street axis



Air humidity %

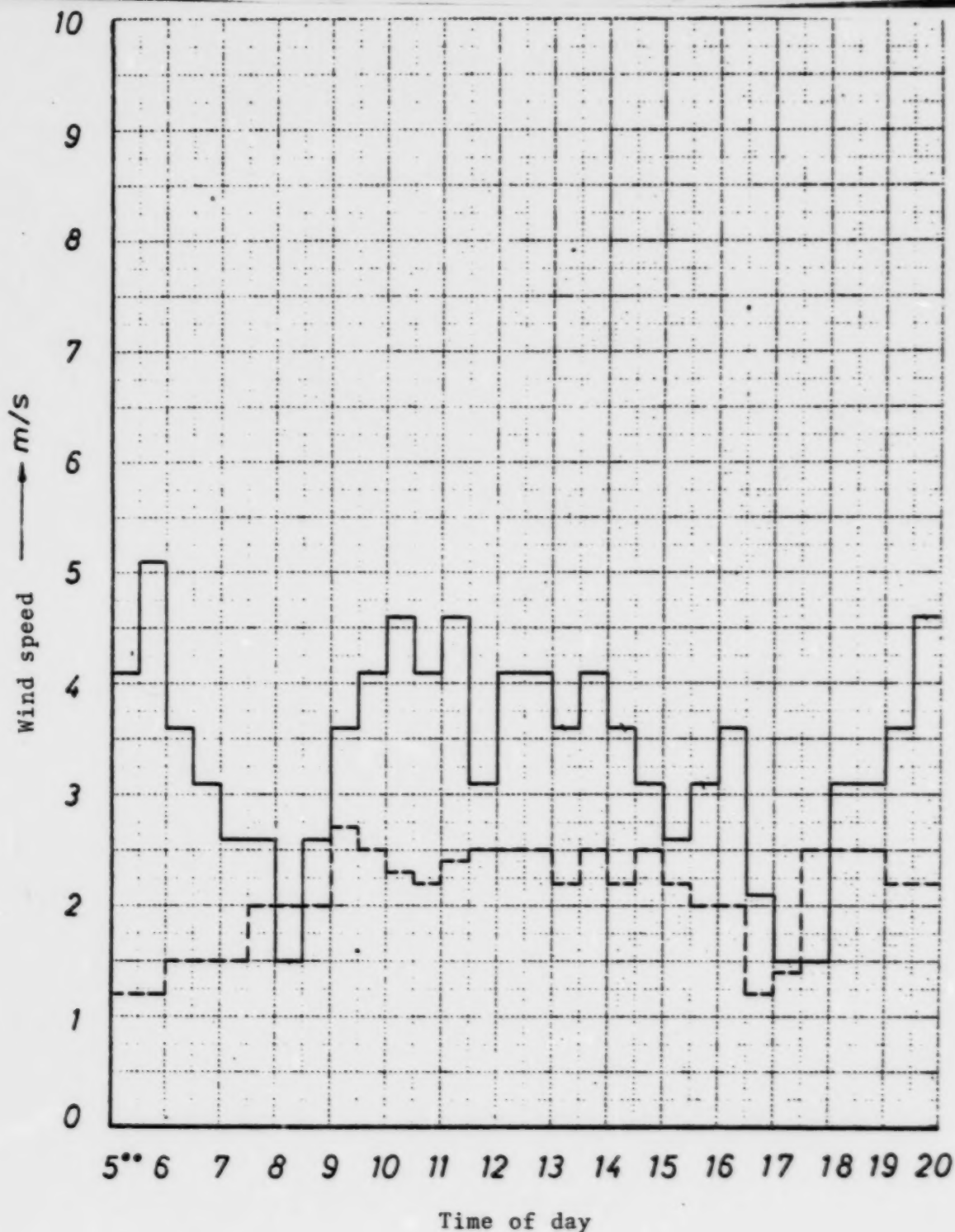
Air temp. °C

Air pressure mb

TÜV  
Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 4  
Date: Nov. 9, 1971



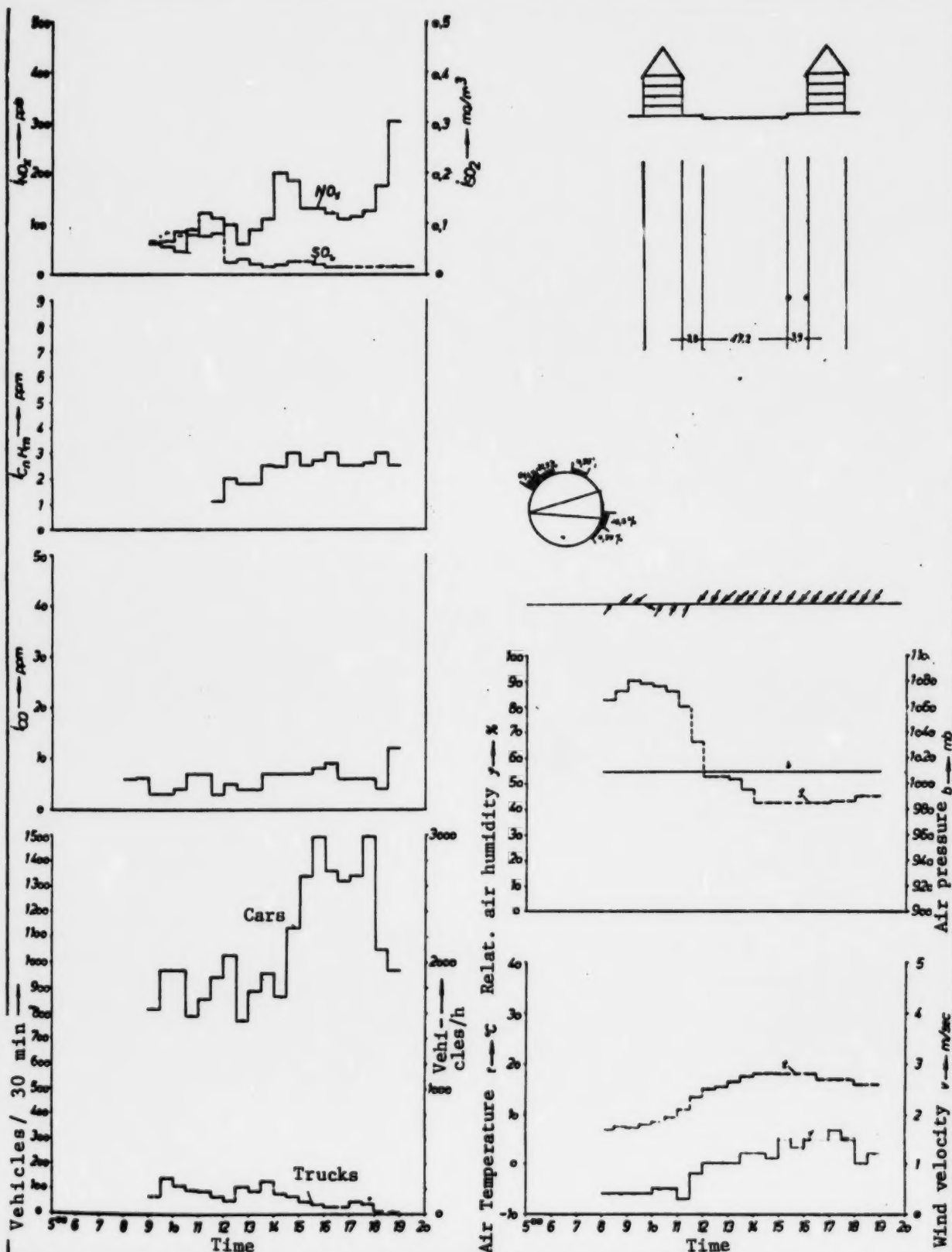
— Global wind speed  
 ---- Local wind speed

TÜV  
 Rheinland

Daily lines for the course of the global and  
 local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 4  
 Date: Nov. 9, 1971





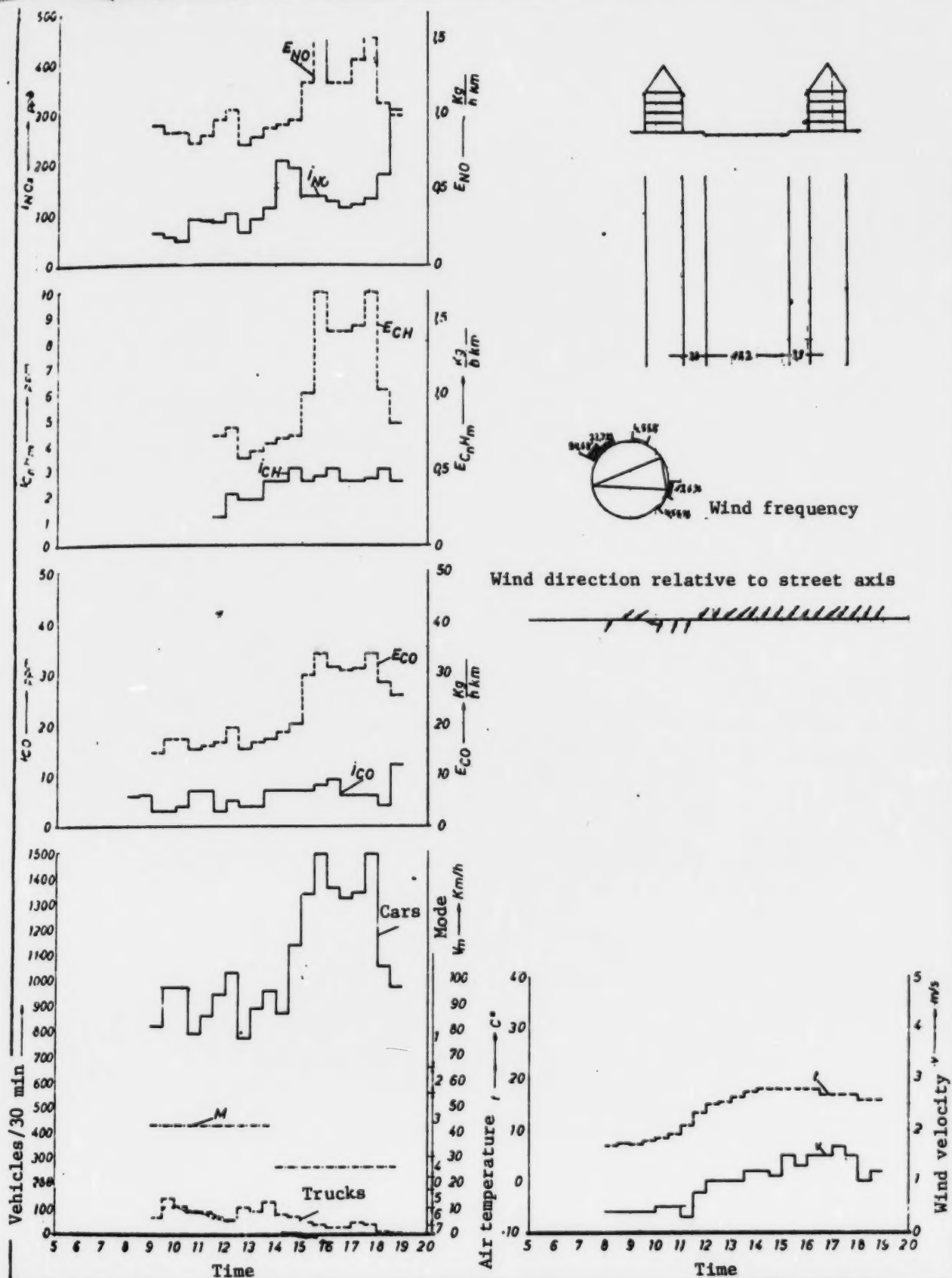
TÜV

Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

Immissions,  
city of Cologne  
Measuring site:

Date: April 20, 1972



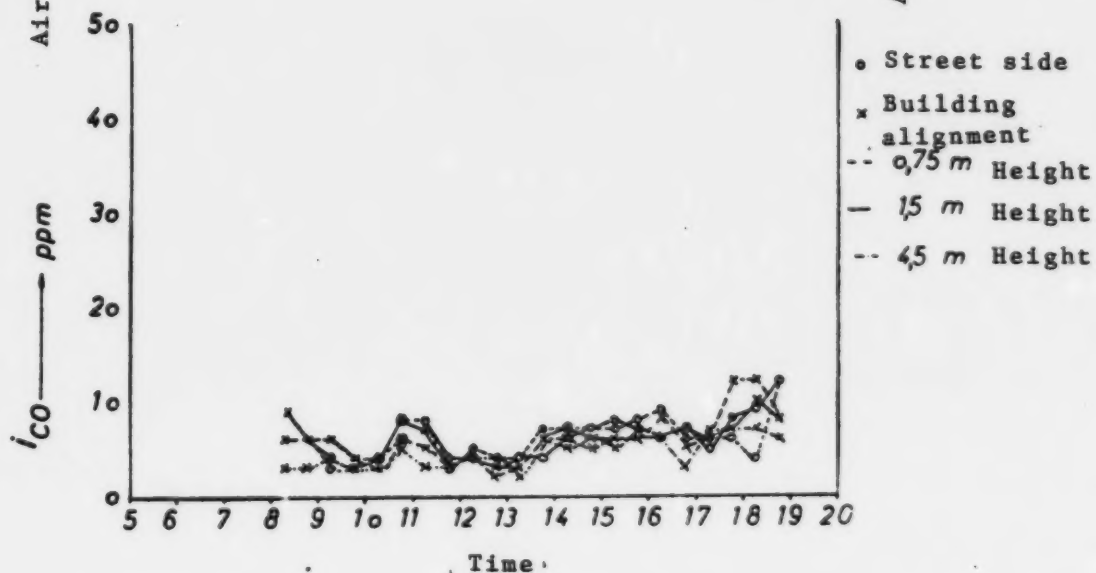
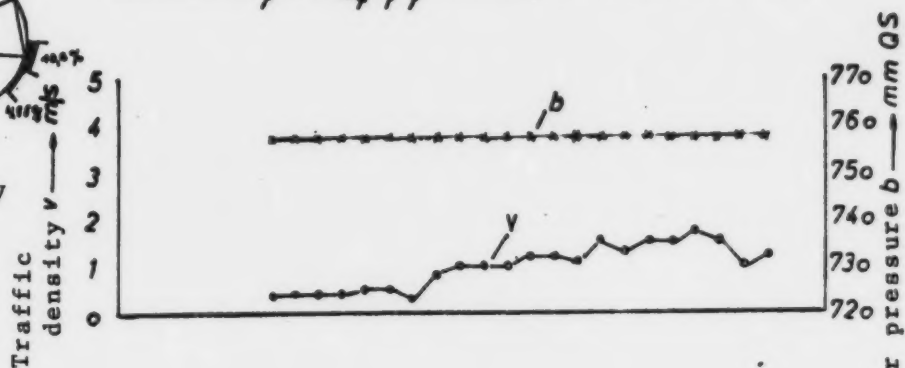
TÜV  
Rheinland

Daily lines for traffic density, exhaust  
gas components (immission, emission) and  
meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 4  
Date: April 20, 1972

Wind  
frequency

Wind direction related to street axis

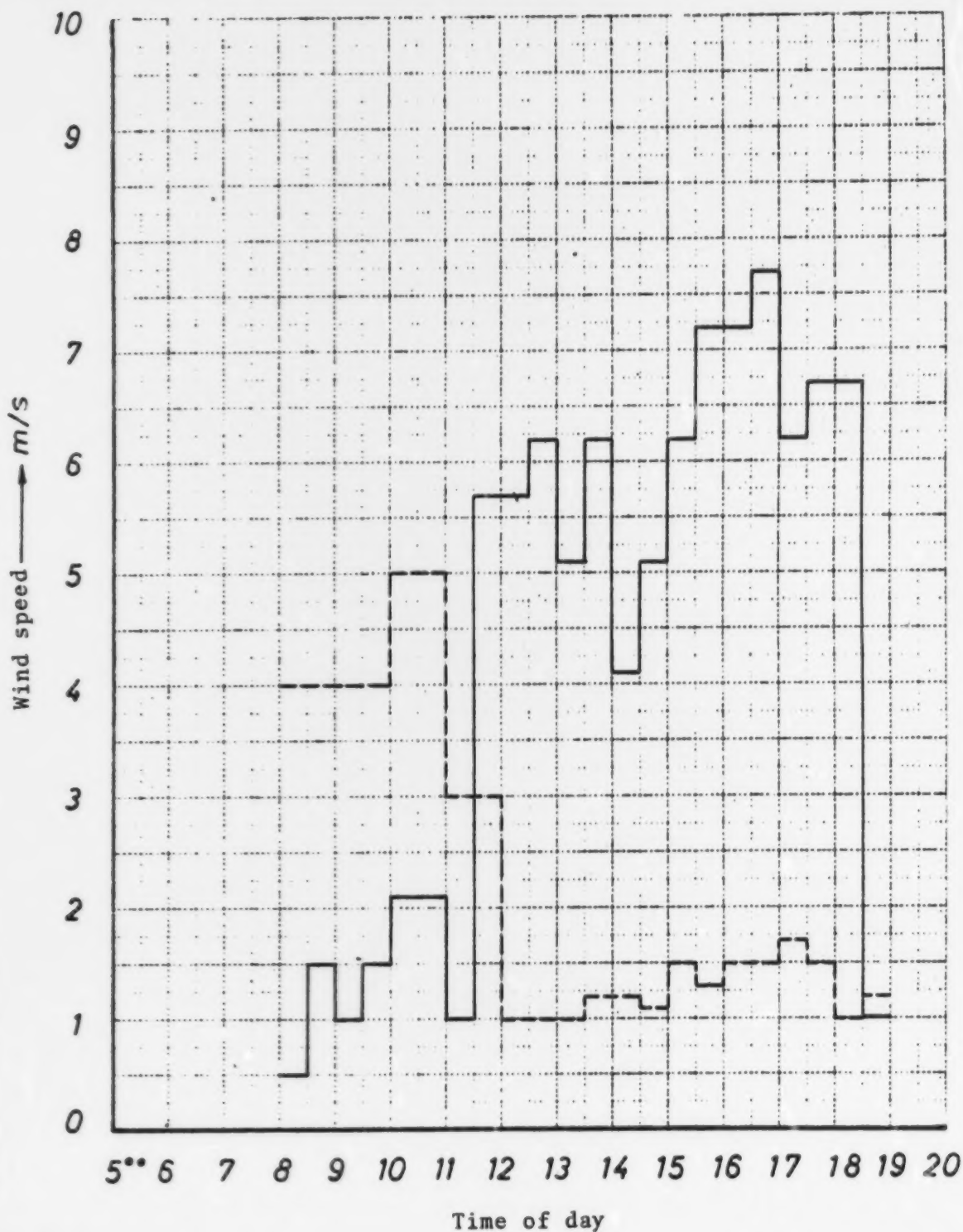


**TÜV**

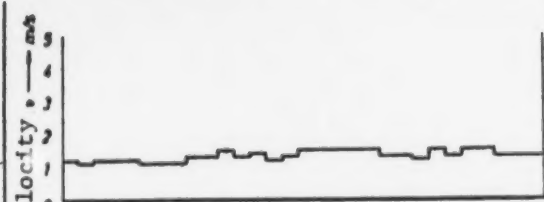
### Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

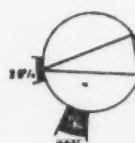
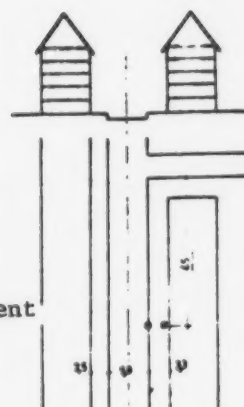
Immissions,  
city of Cologne  
Measuring site: 4  
Date: April 20, 1972





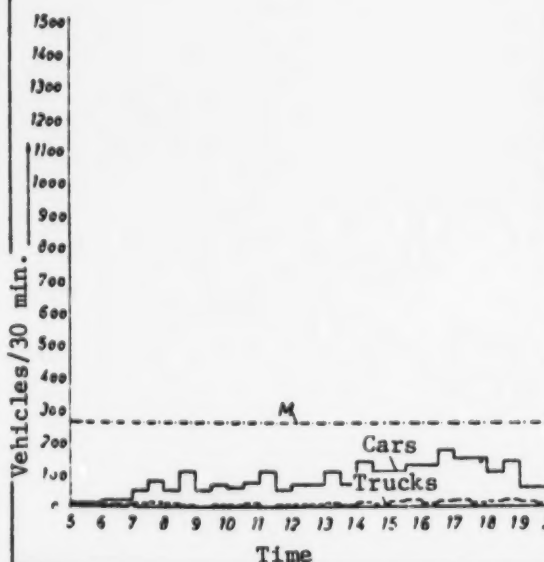
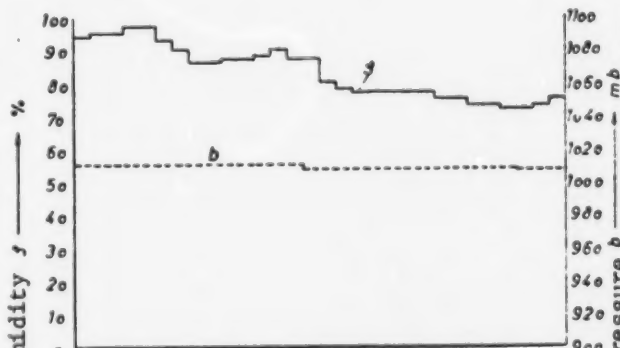


• Building alignment  
• Street side  
--- 0.75 m Height  
— 1.5 m Height  
--- 4.5 m Height

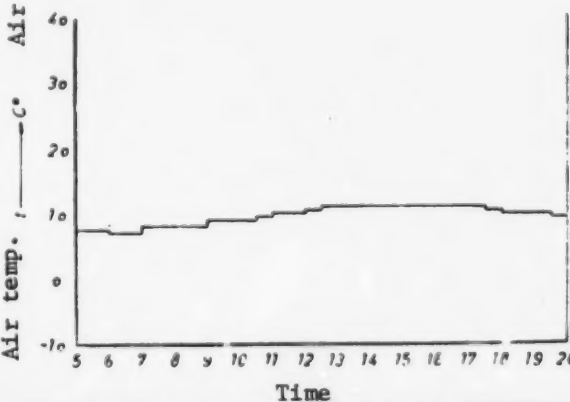


Wind frequency

Wind direction relative to street axis



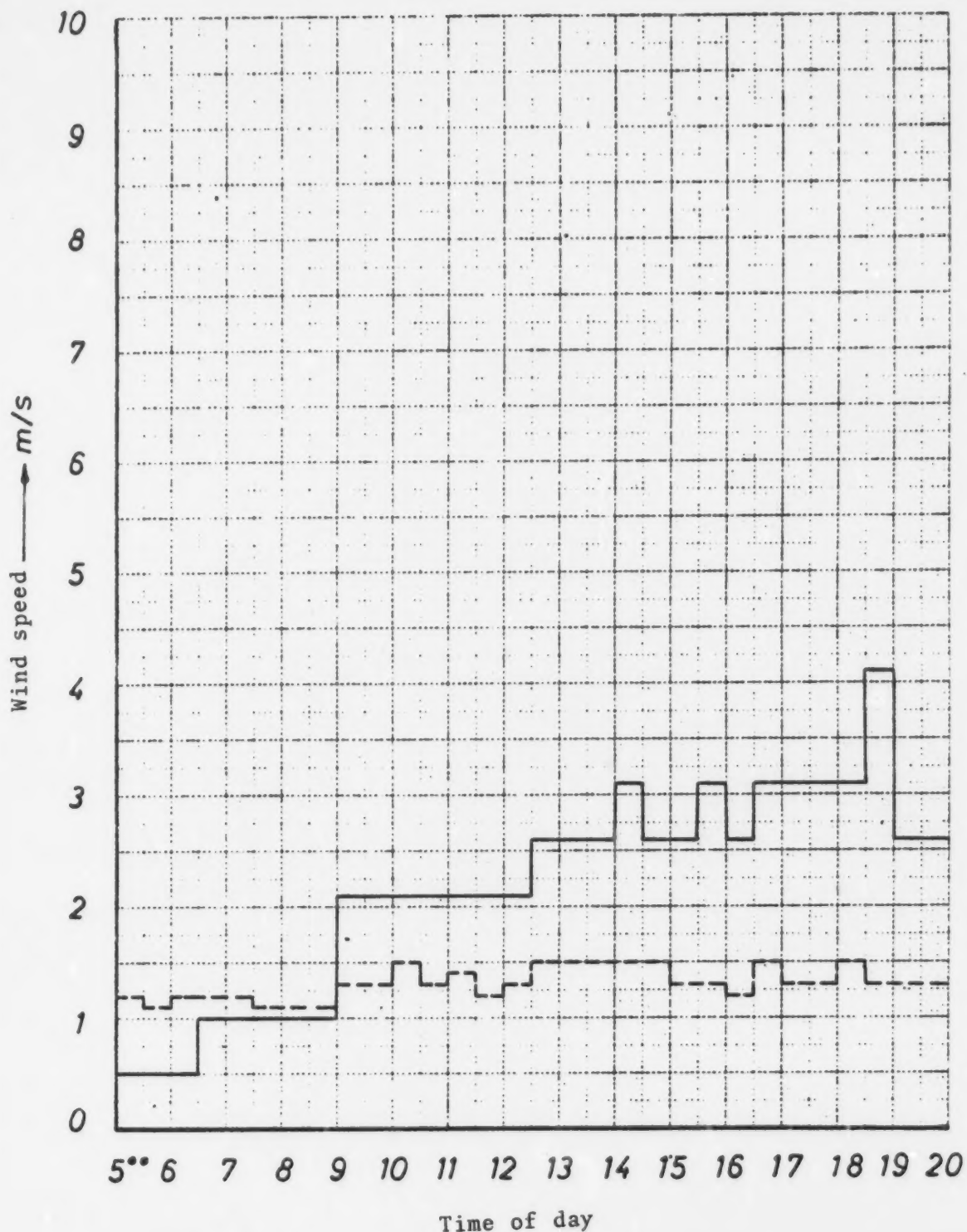
Mode M  
Vm  
Km/h

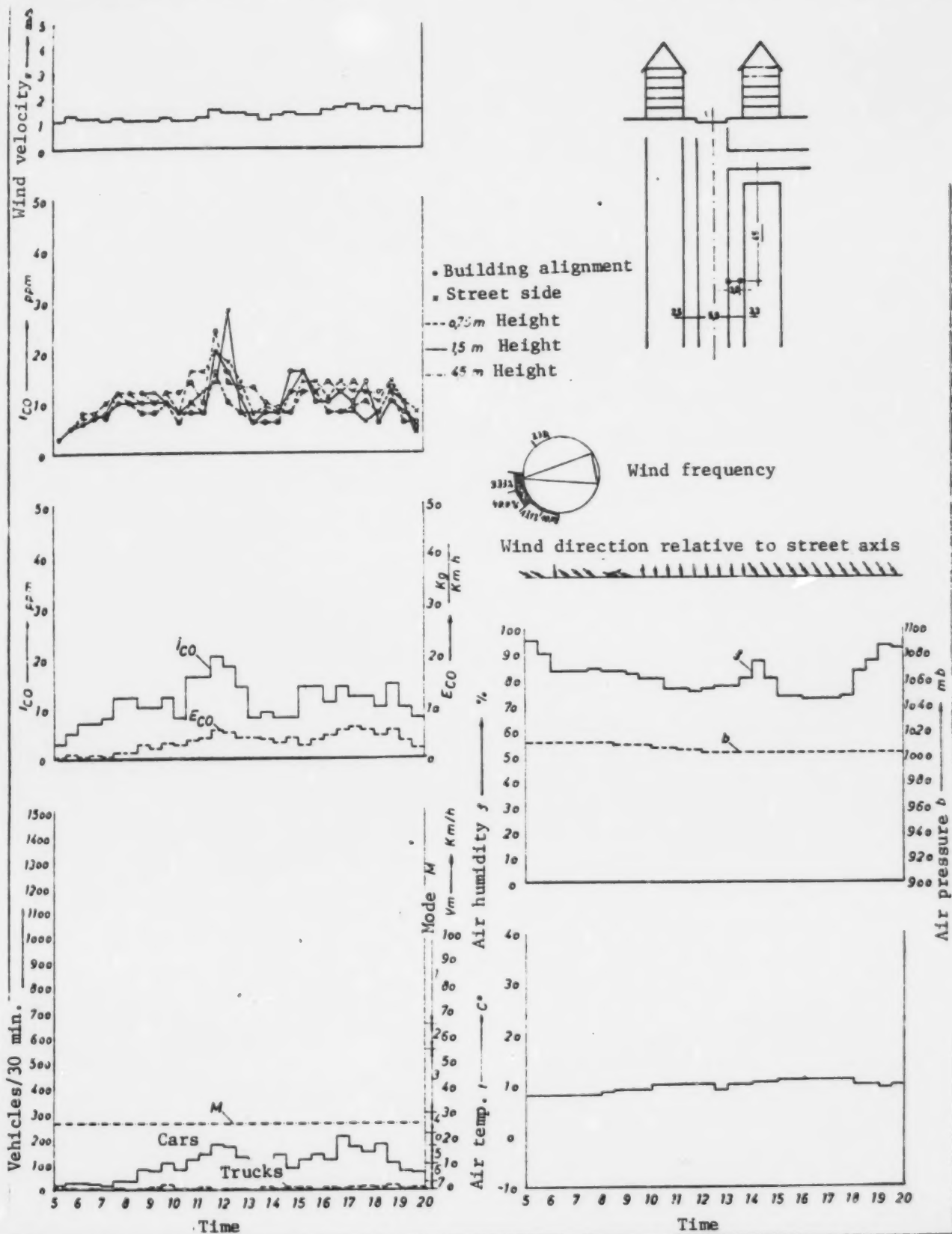


TÜV  
Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 5  
Date: Nov. 15, 1971

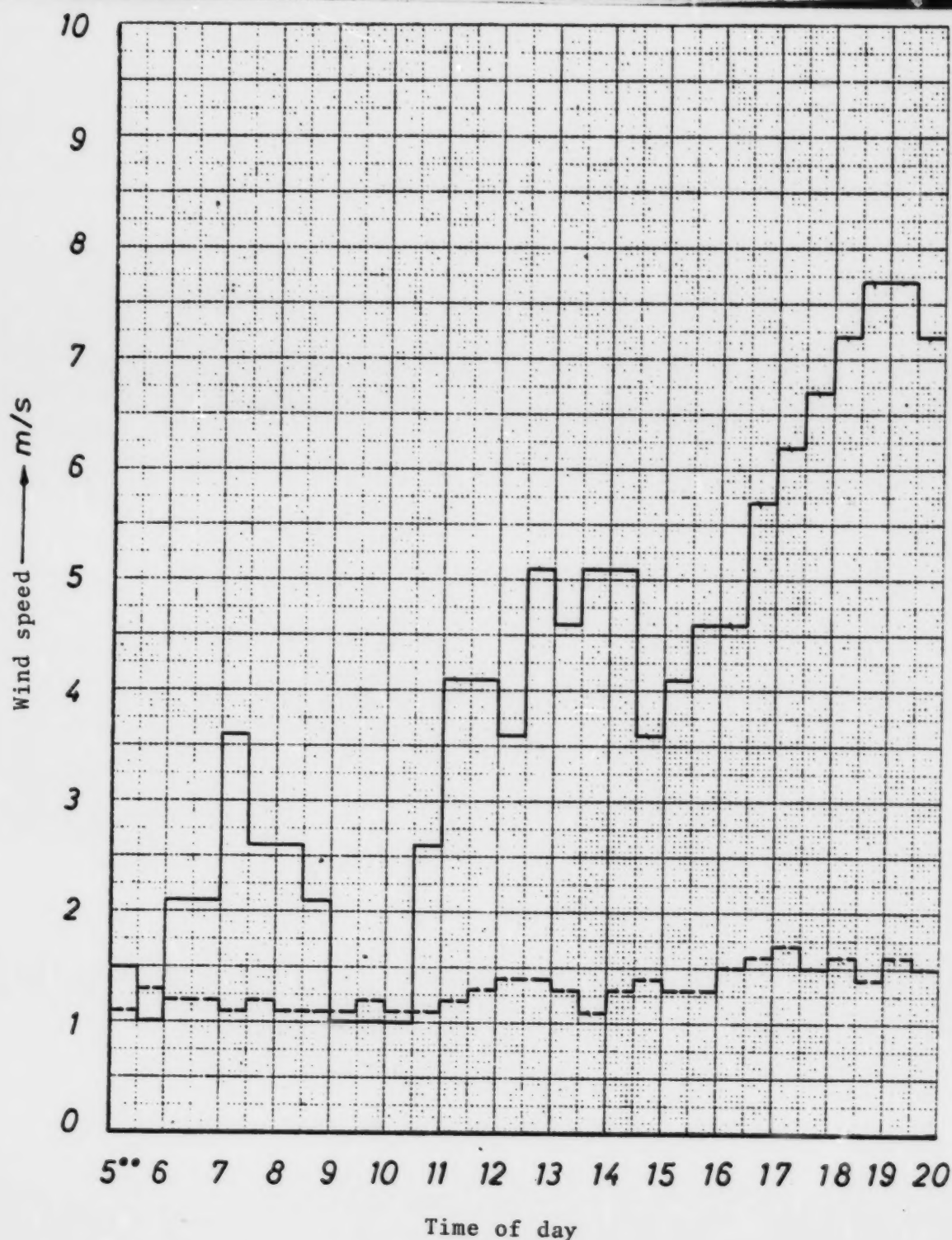




TÜV  
Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 5  
Date: Nov. 16, 1971

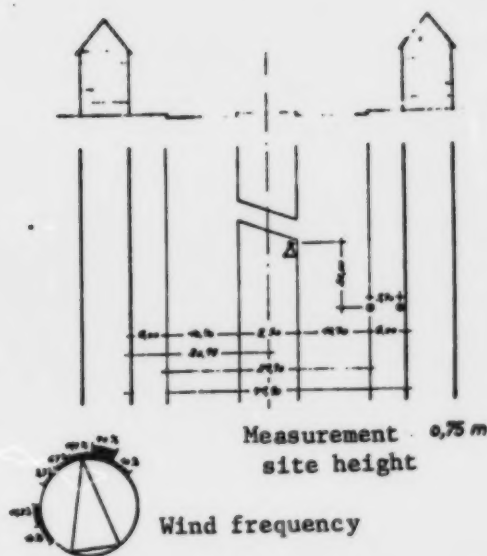
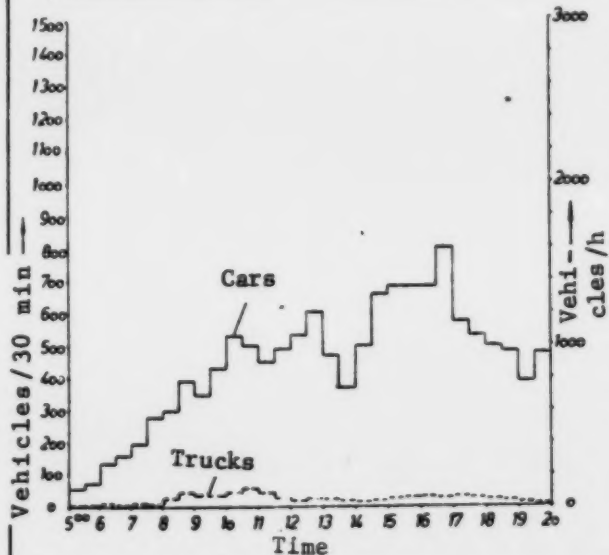
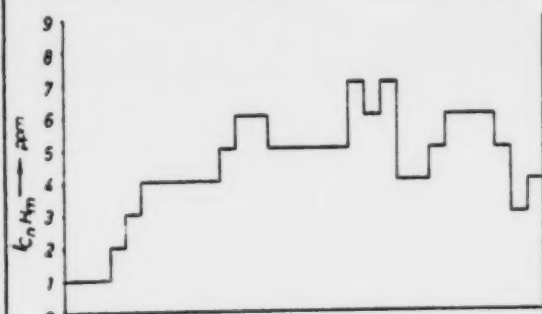
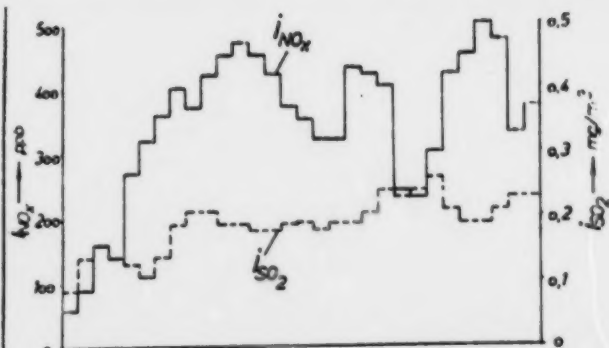


TÜV  
Rheinland

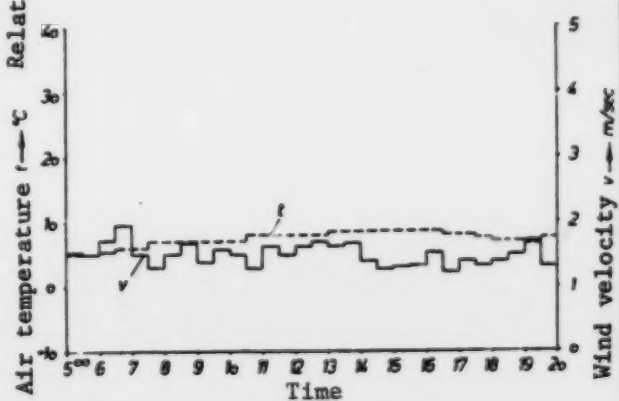
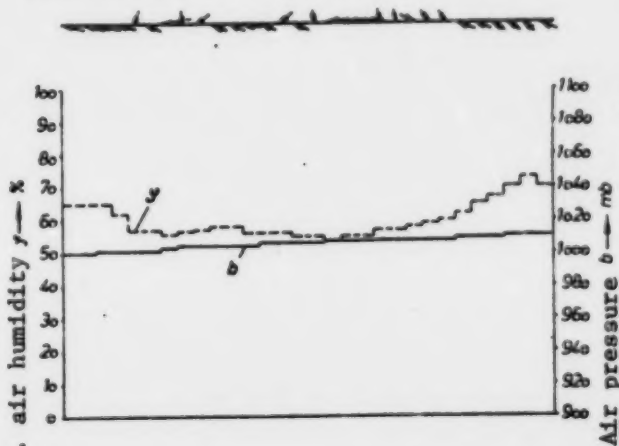
Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 5  
Date: Nov. 16, 1971





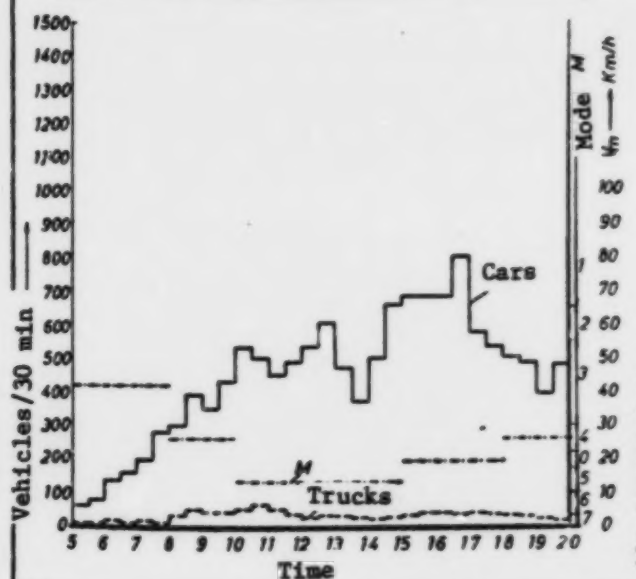
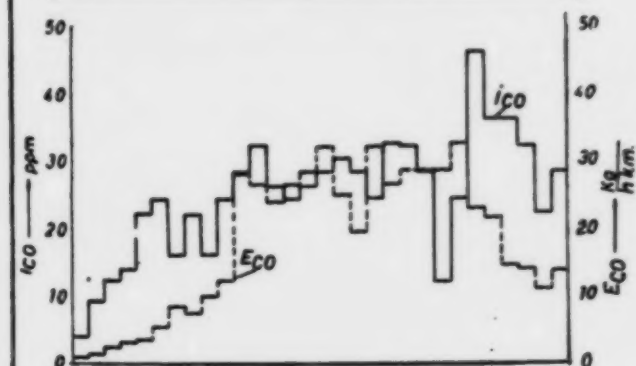
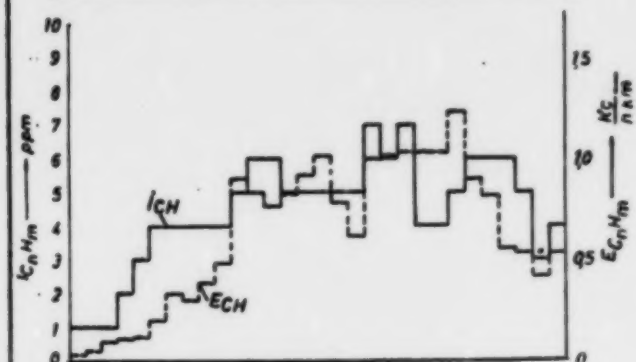
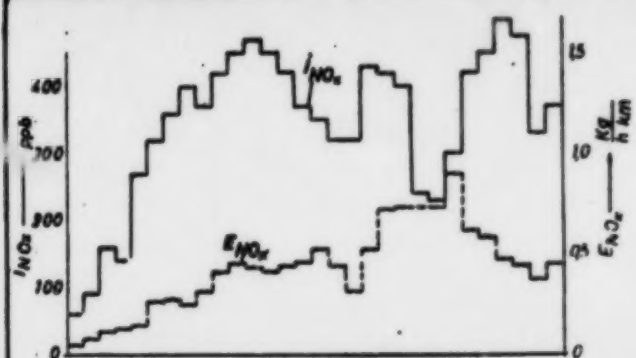
Wind direction relative to street axis



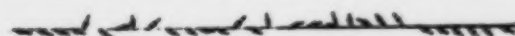
TÜV  
Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

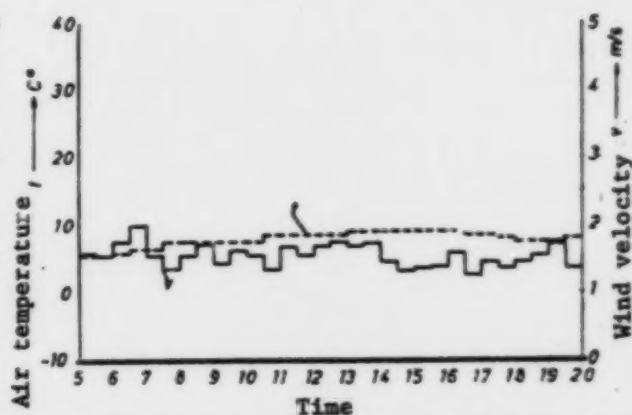
Immissions,  
city of Cologne  
Measuring site: 6  
Date: Dec. 3, 1971



Wind direction relative to street axis



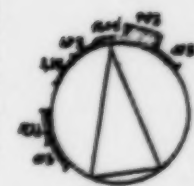
Wind frequency



TÜV  
Rheinland

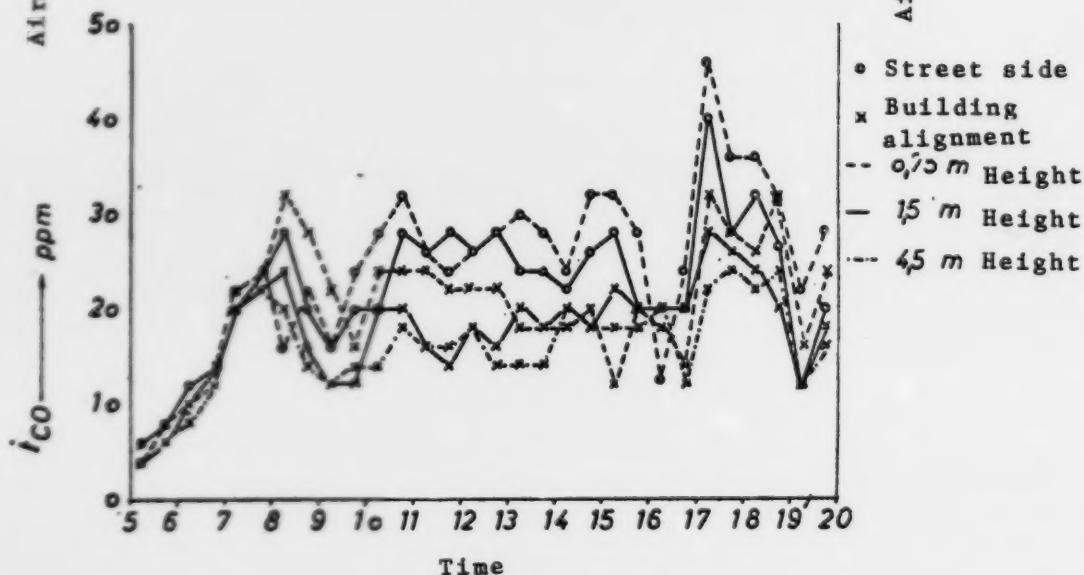
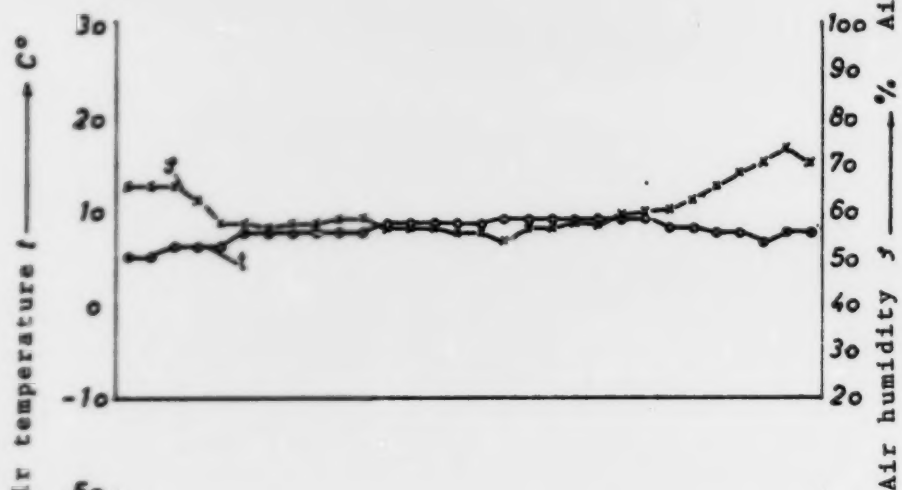
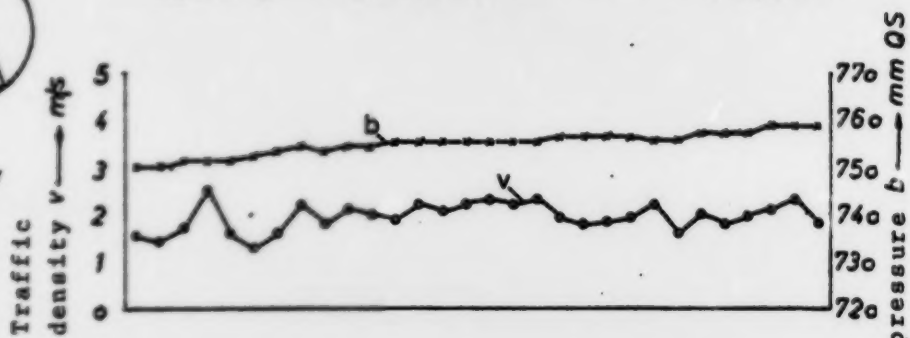
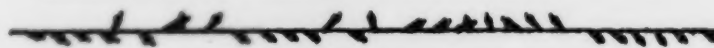
Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 6  
Date: Dec. 3, 1971



Wind frequency

Wind direction related to street axis



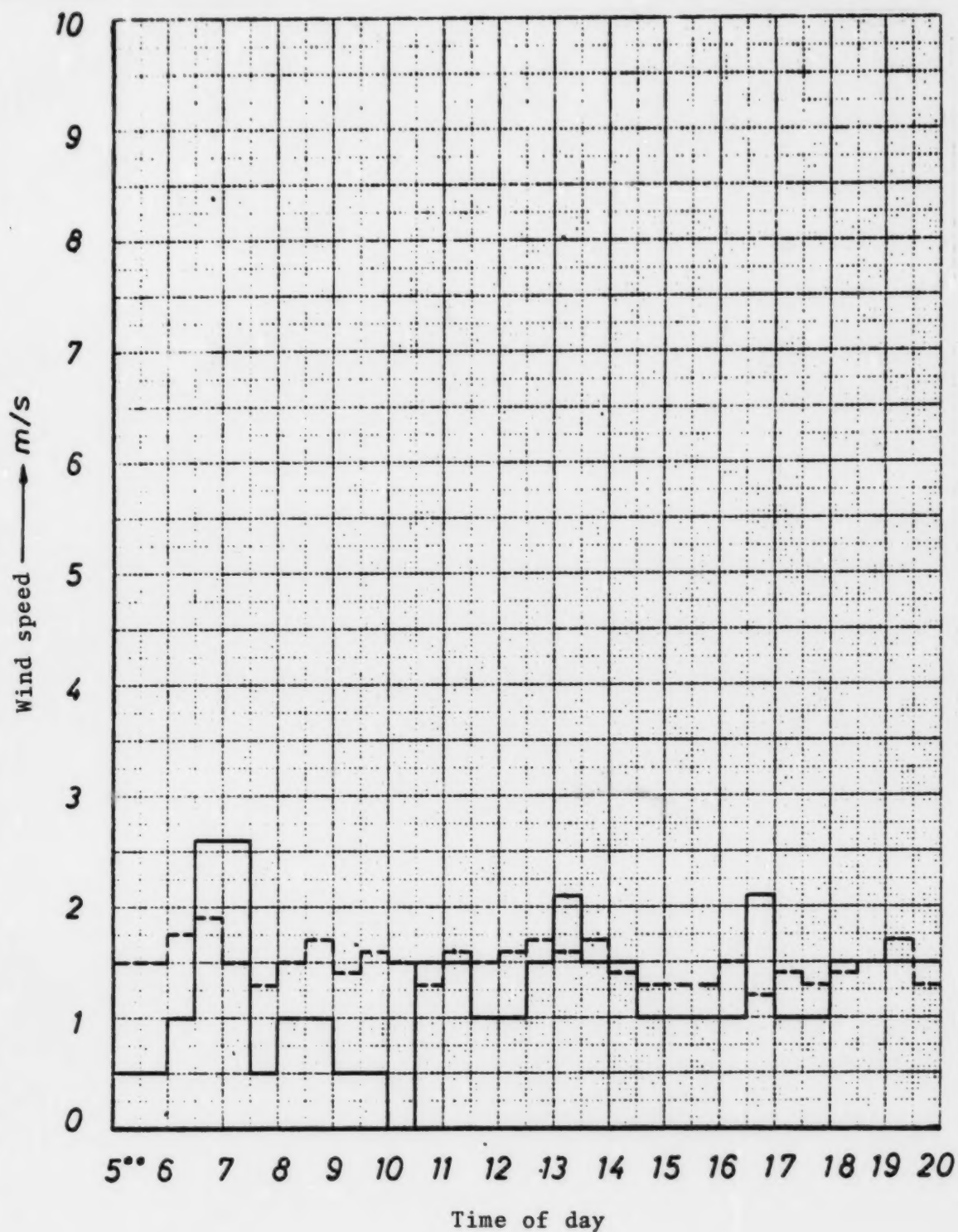
- Street side
- x Building alignment
- 0.75 m Height
- 15 m Height
- 45 m Height

TÜV

Reinhold

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 6  
Date: Dec. 3, 1971

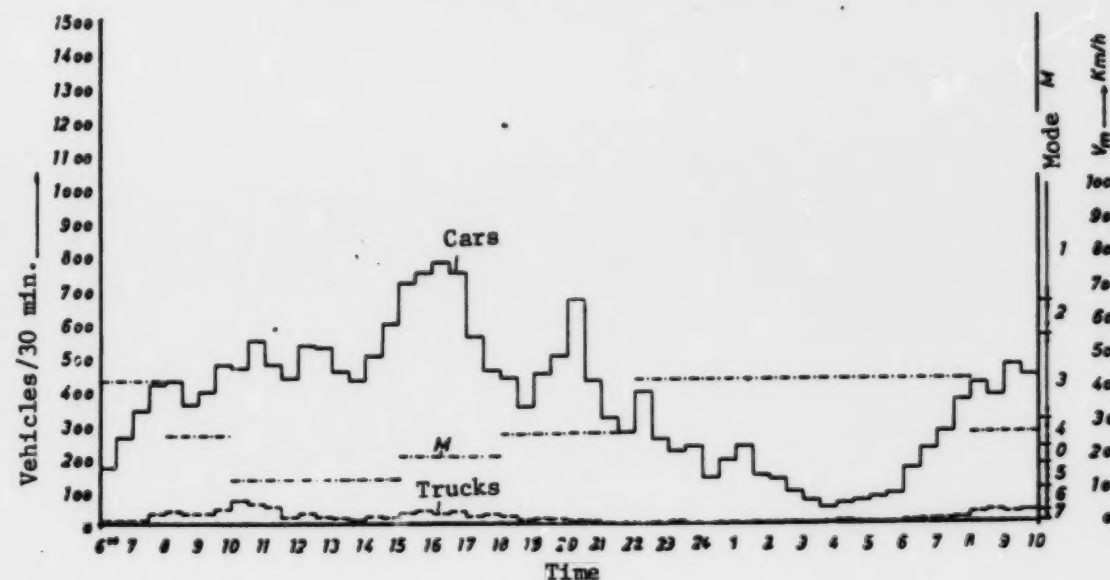
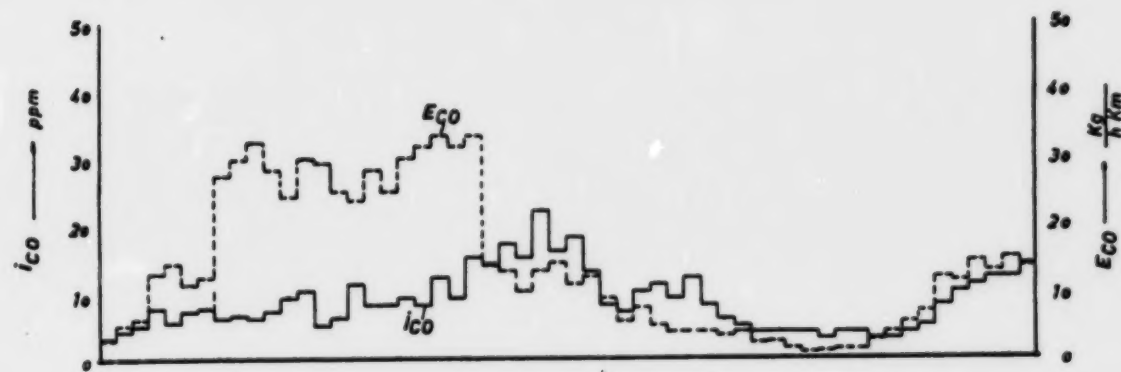


TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed

Immissions,  
city of Cologne  
Measuring site: 6  
Date: Dec. 3, 1971



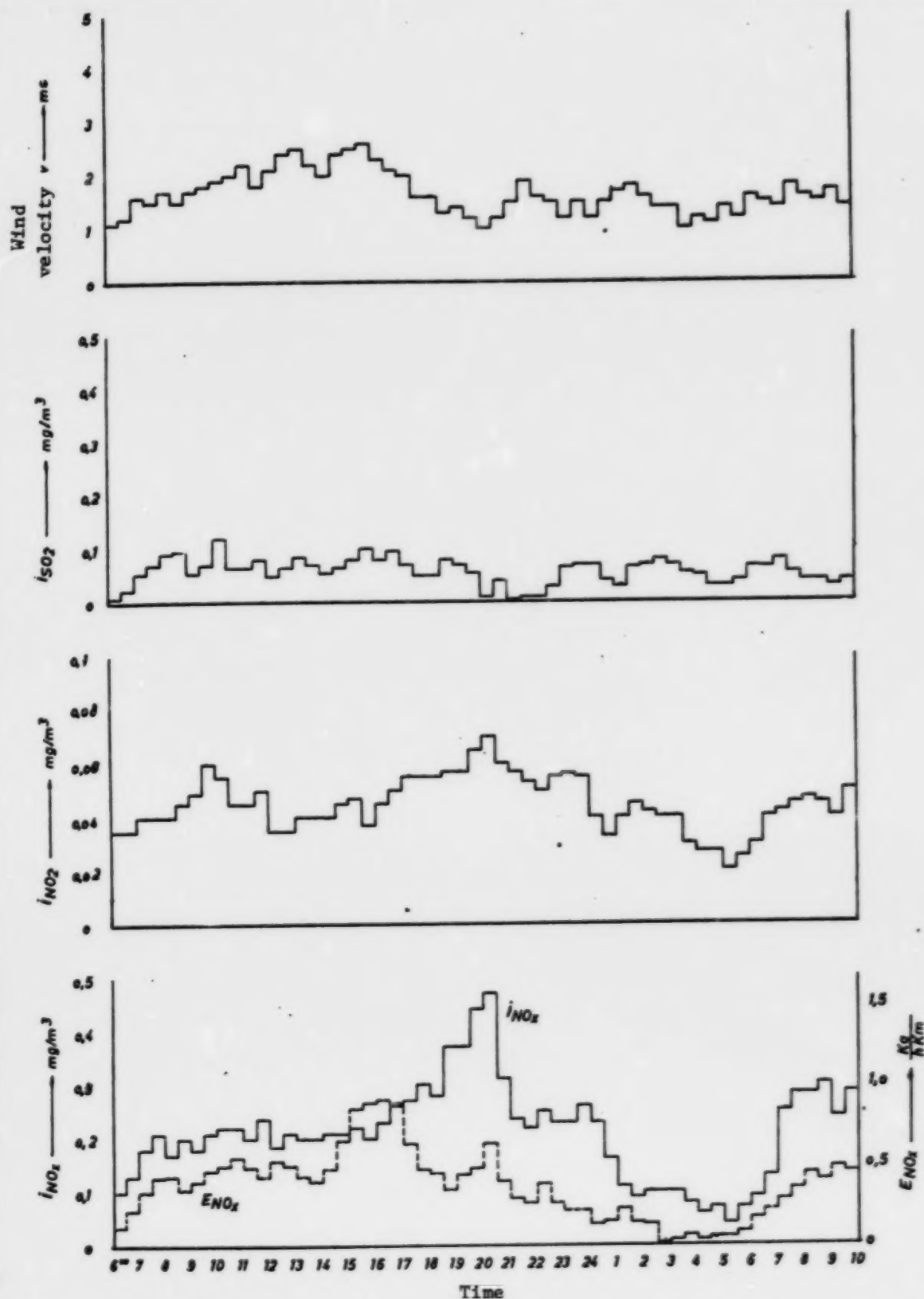


Daily variation lines for traffic density and exhaust gas components CO, C<sub>n</sub>, H<sub>m</sub> (Immissions and Emissions)

Immissions,  
city of Cologne  
Measuring site: 6

Sheet 1  
out of 4

Date: June 15-16, 1972

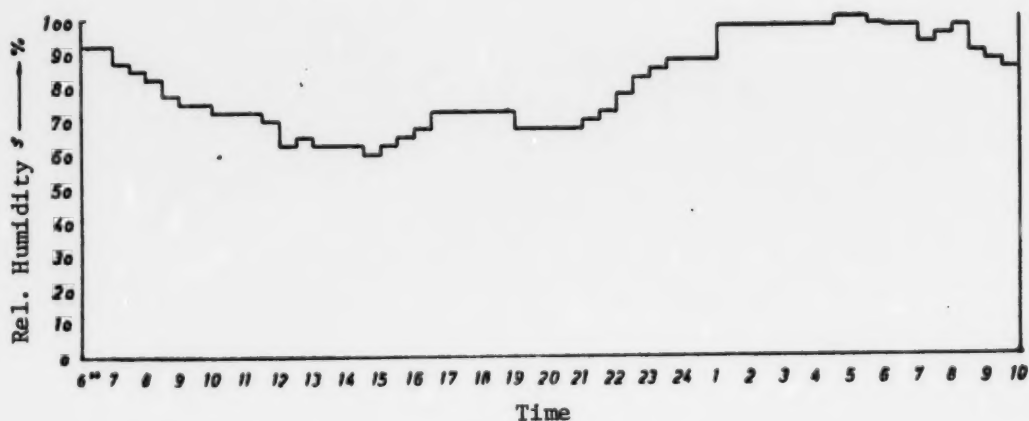
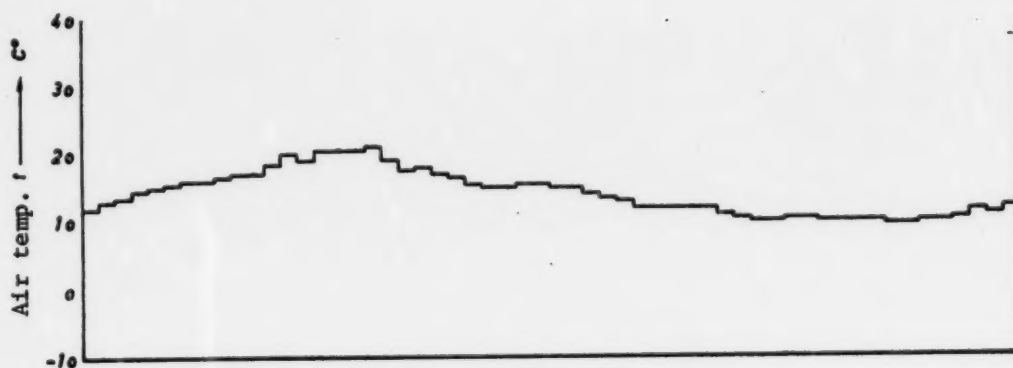
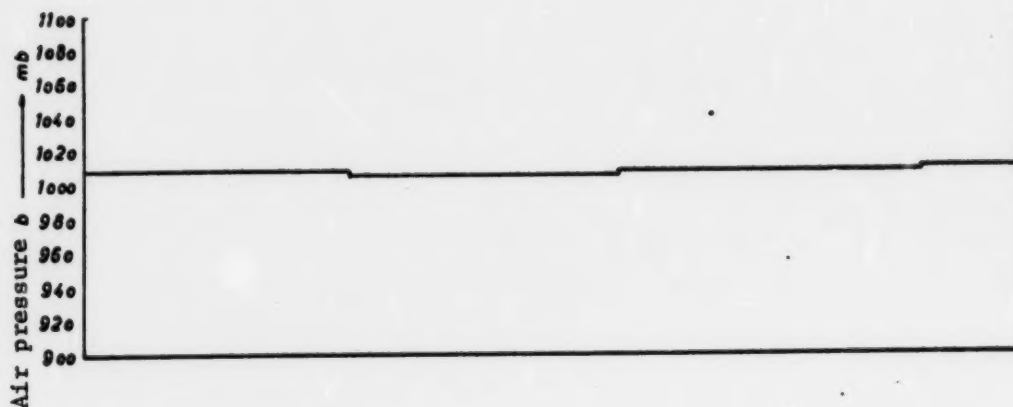


TÜV  
Rheinland

Daily variation lines. Exhaust gas components  $NO_x$  (Immissions and Emissions),  $NO_2$ ,  $SO_2$  and wind velocity.

Immissions,  
city of Cologne  
Measuring site: 6  
Date: Jun. 15-16, 1972

Sheet 2  
out of 4



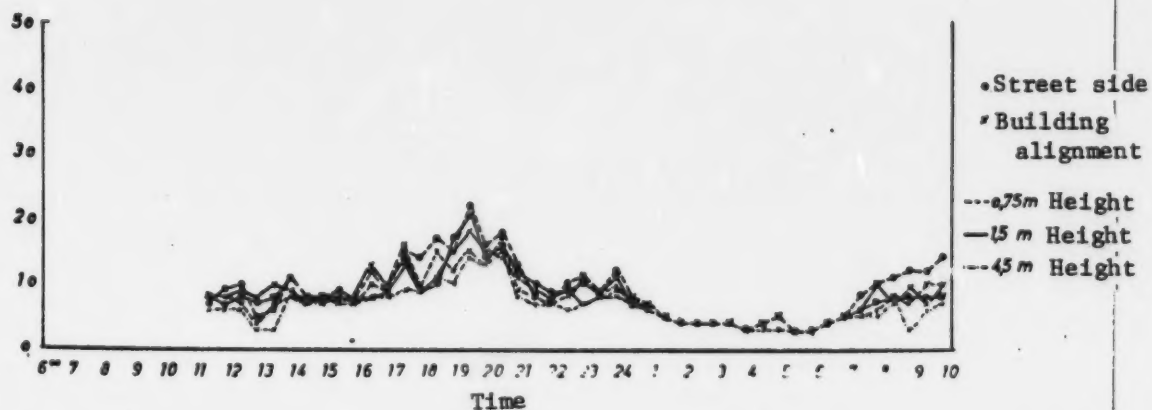
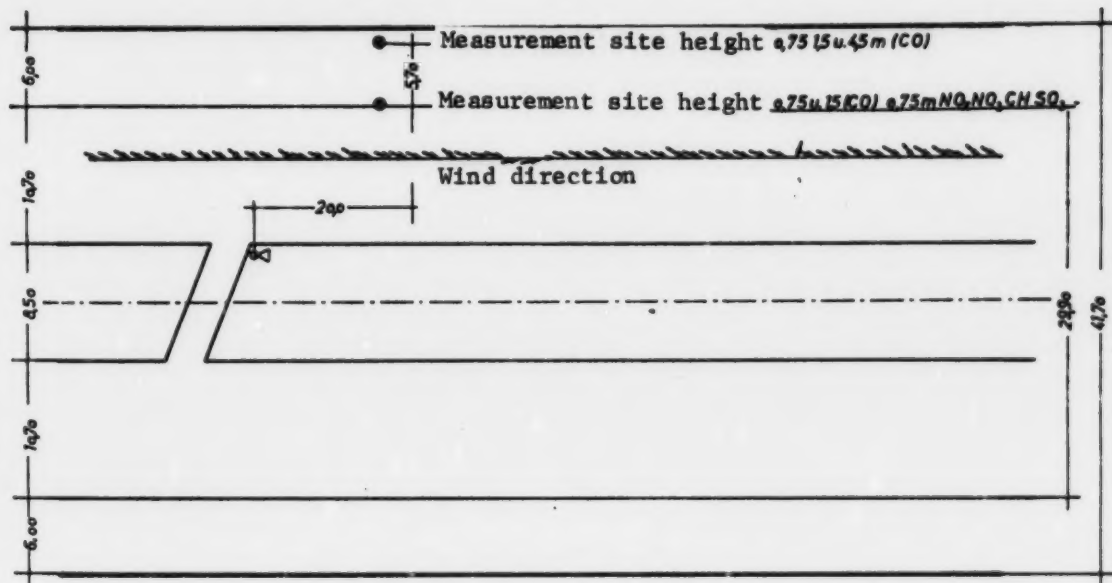
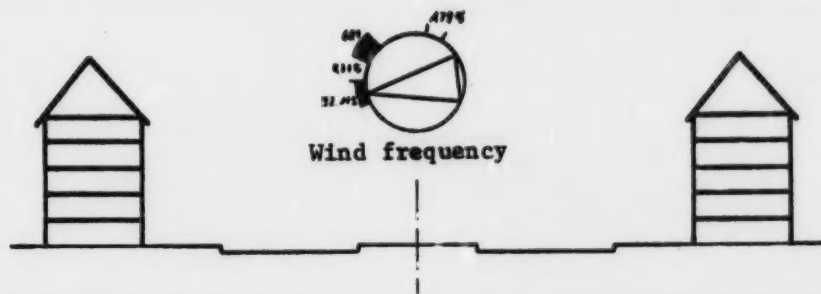
TUV  
Rheinland

Daily lines for the meteorological  
variables

Immissions,  
city of Cologne  
Measuring site:

Date: June 15-16, 1972

Sheet 3  
out of 6



TÜV  
Rheinland

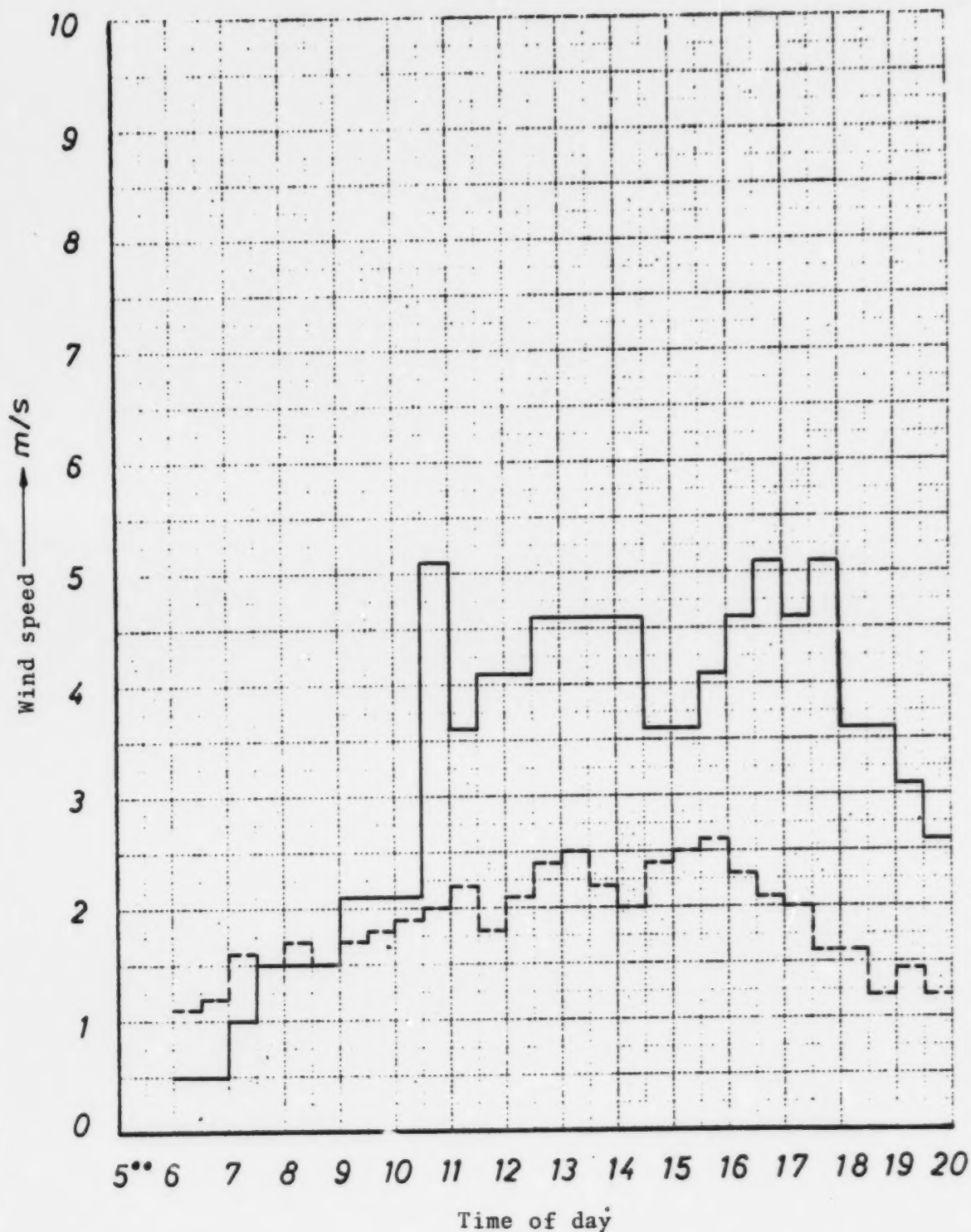
Daily lines for variations in wind direction and CO concentration at various heights

Immissions,  
city of Cologne  
Measuring site:

Date: June 15-16, 1972

Sheet 4  
out of 4

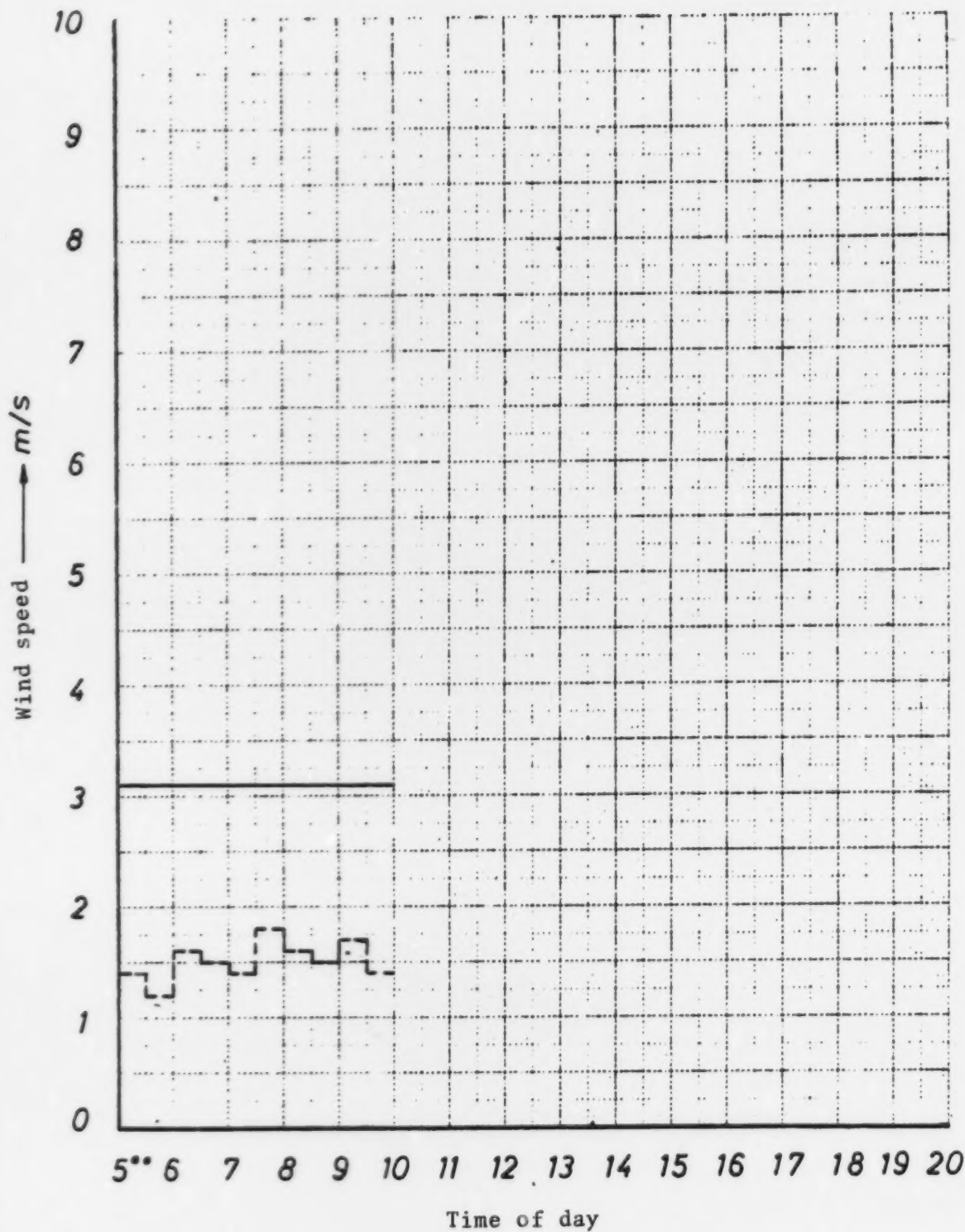




TÜV  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

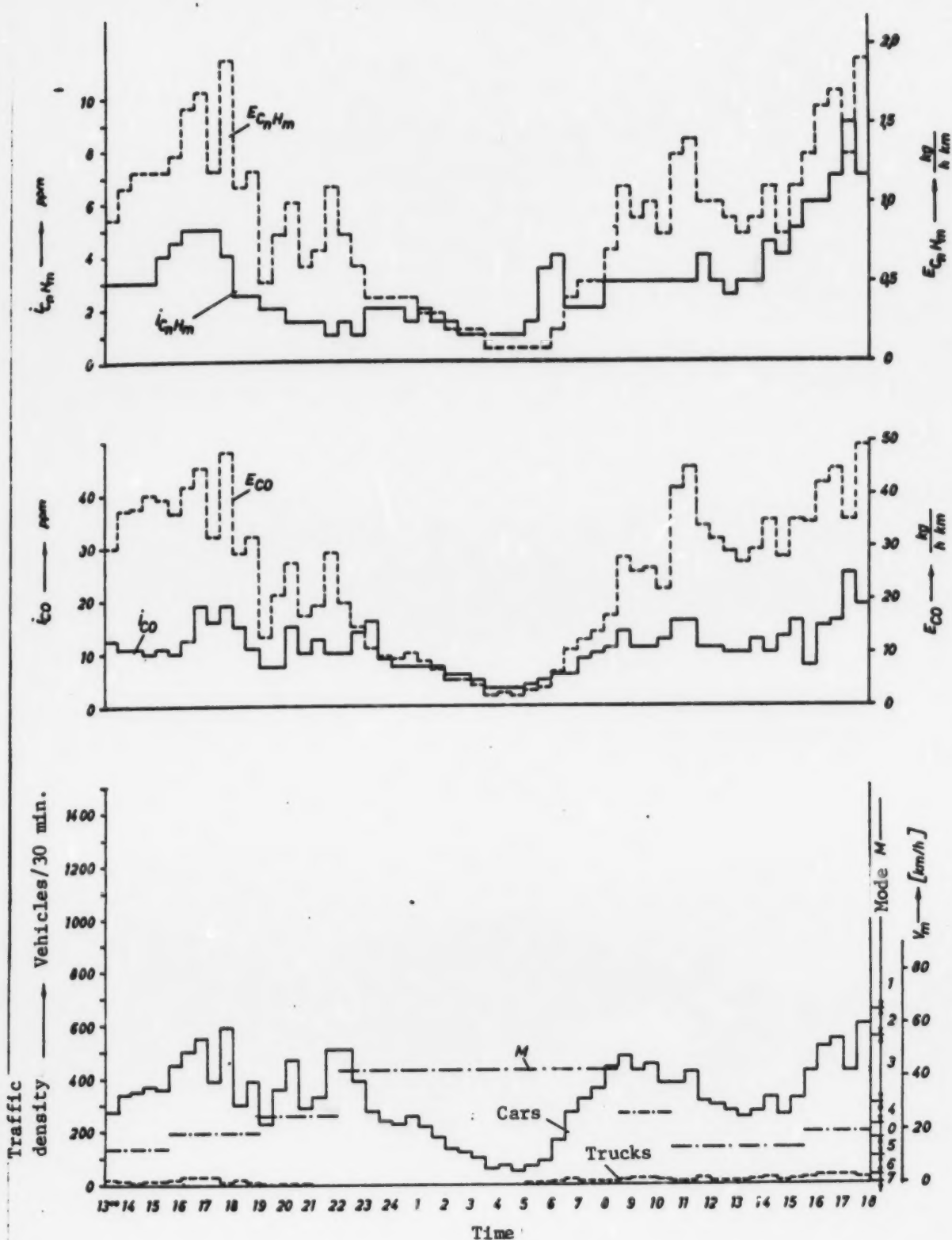
Immissions,  
 city of Cologne  
 Measuring site: 6  
 Date: June 15, 1972



TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 6  
Date: June 16, 1972

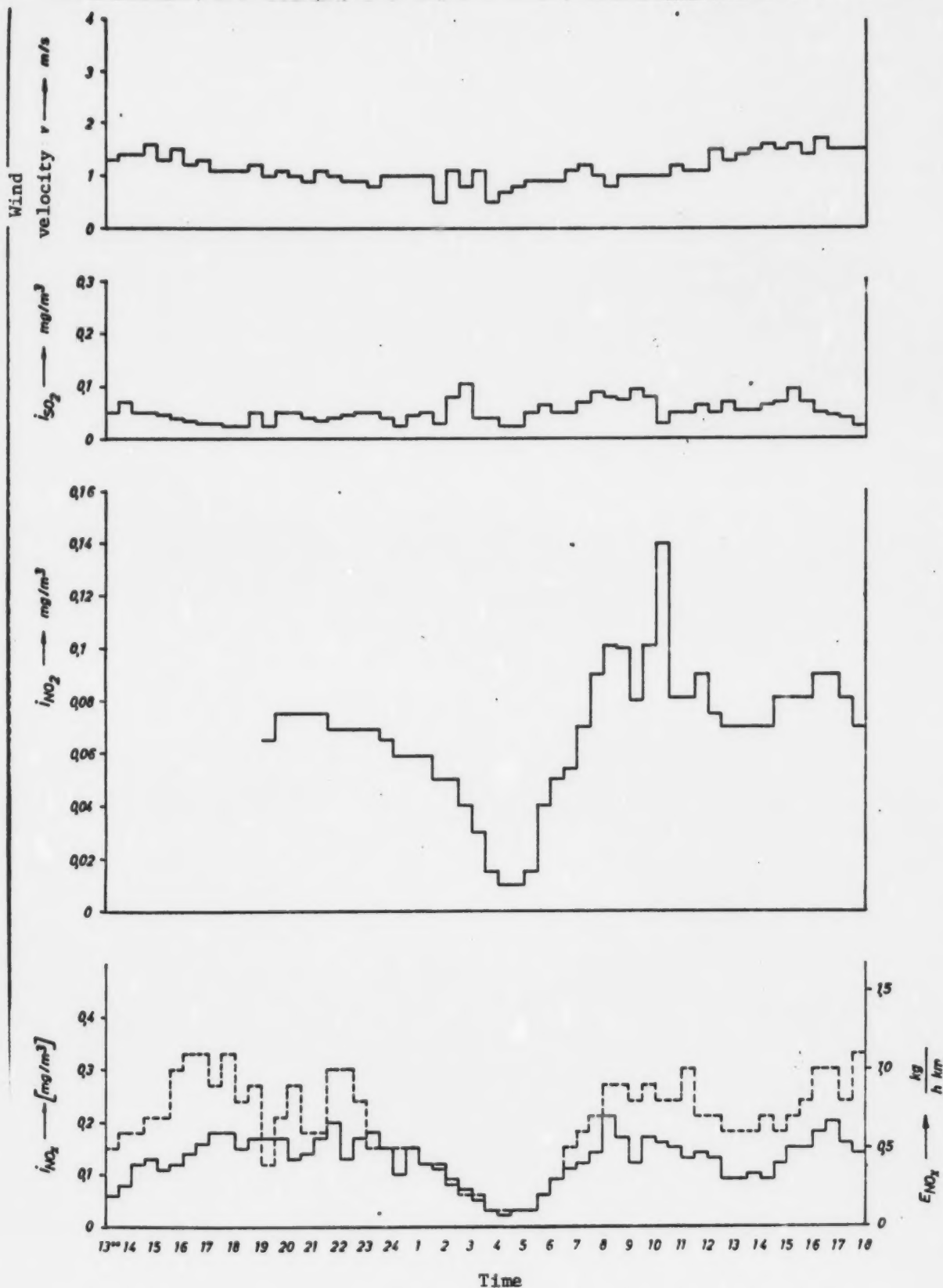


Daily variation lines for traffic density and exhaust gas components CO,  $C_n$ ,  $H_m$  (Immissions and Emissions)

Immissions,  
city of Cologne  
Measuring site:

Sheet 1  
out of 4

Date: July 13-14, 1972



TÜV  
Rheinland

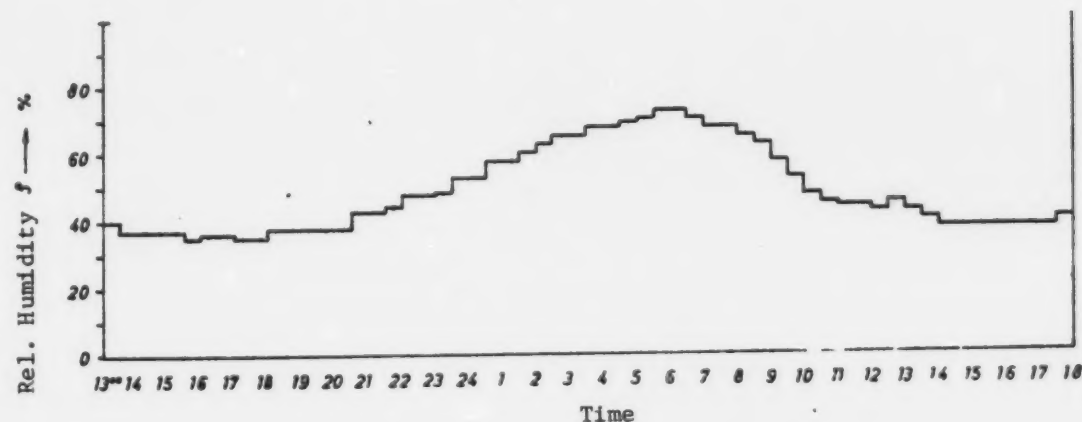
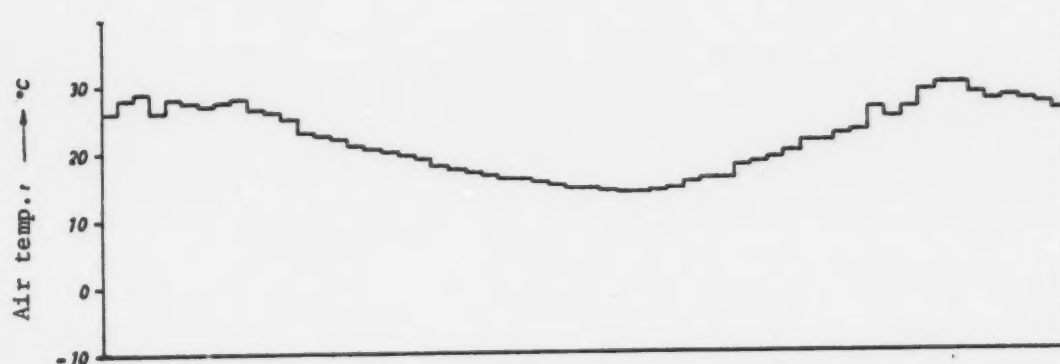
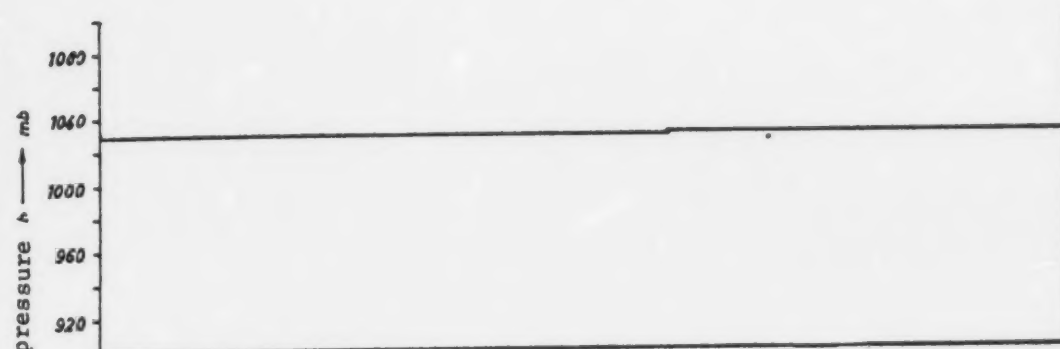
Daily variation lines. Exhaust gas components  $NO_x$  (Immissions and Emissions),  $NO_2$ ,  $SO_2$  and wind velocity.

Immissions,  
city of Cologne  
Measuring site: 6

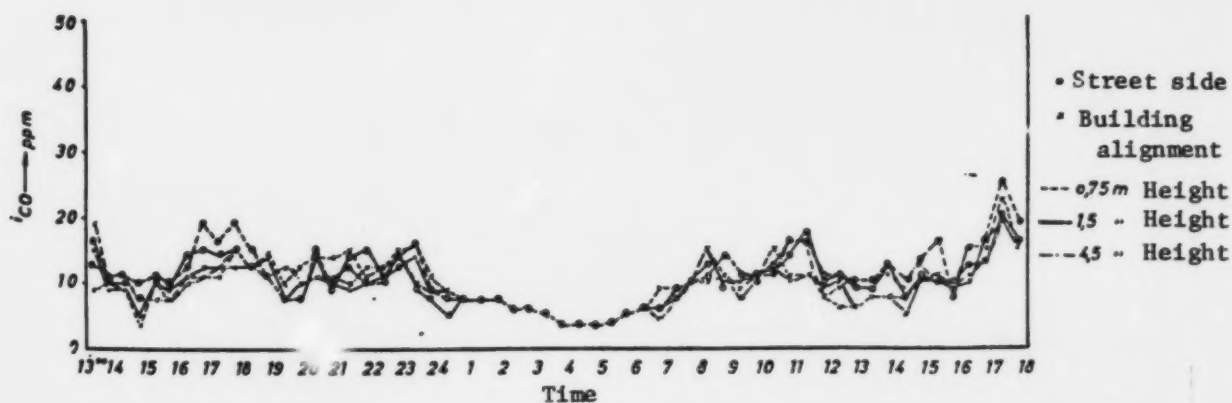
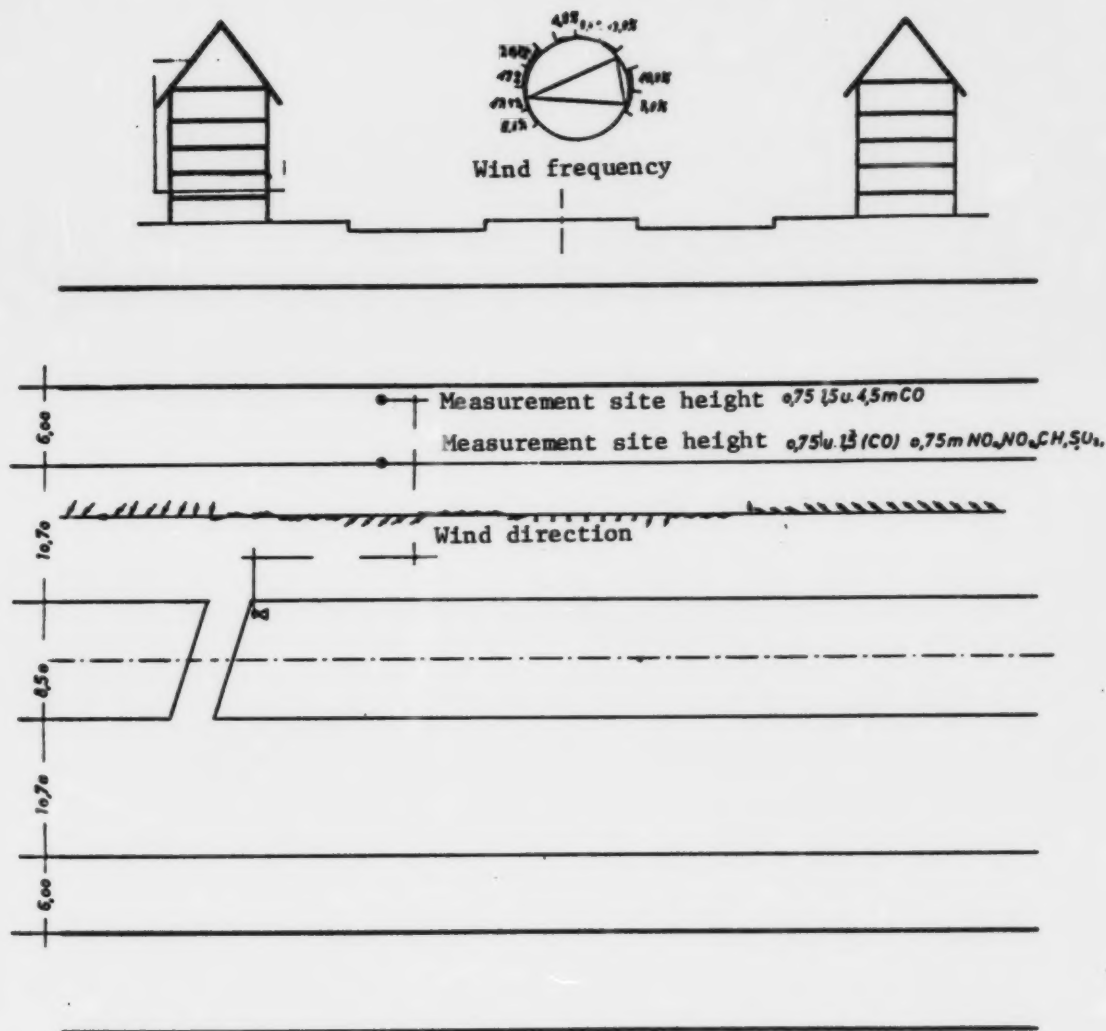
Date: July 13-14, 1972

Sheet 2  
out of 4

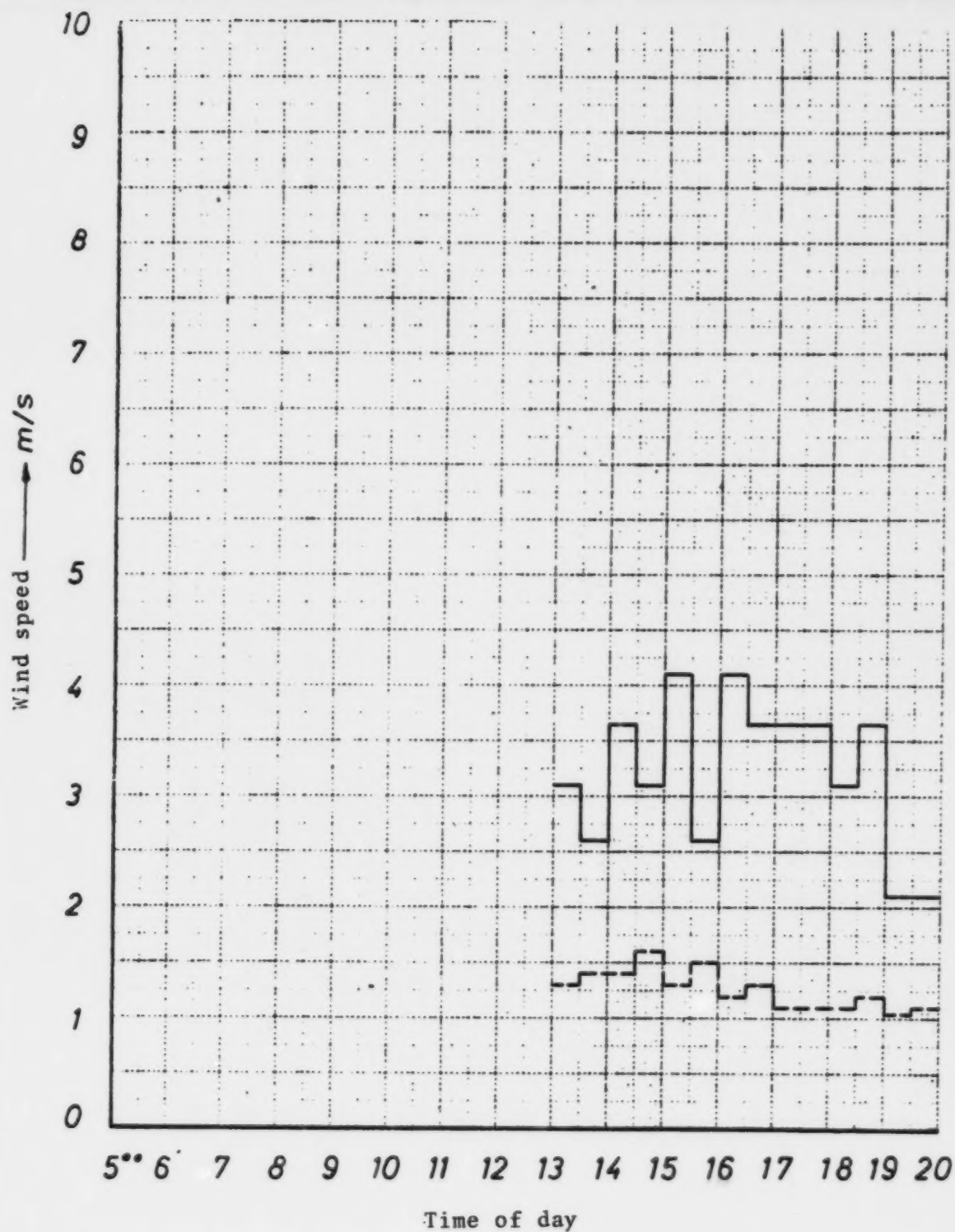




|                         |                                              |                                                                               |                     |
|-------------------------|----------------------------------------------|-------------------------------------------------------------------------------|---------------------|
| <b>TÜV</b><br>Rheinland | Daily lines for the meteorological variables | Immissions,<br>city of Cologne<br>Measuring site: 6<br>Date: July 13-14, 1972 | Sheet 3<br>out of 4 |
|-------------------------|----------------------------------------------|-------------------------------------------------------------------------------|---------------------|



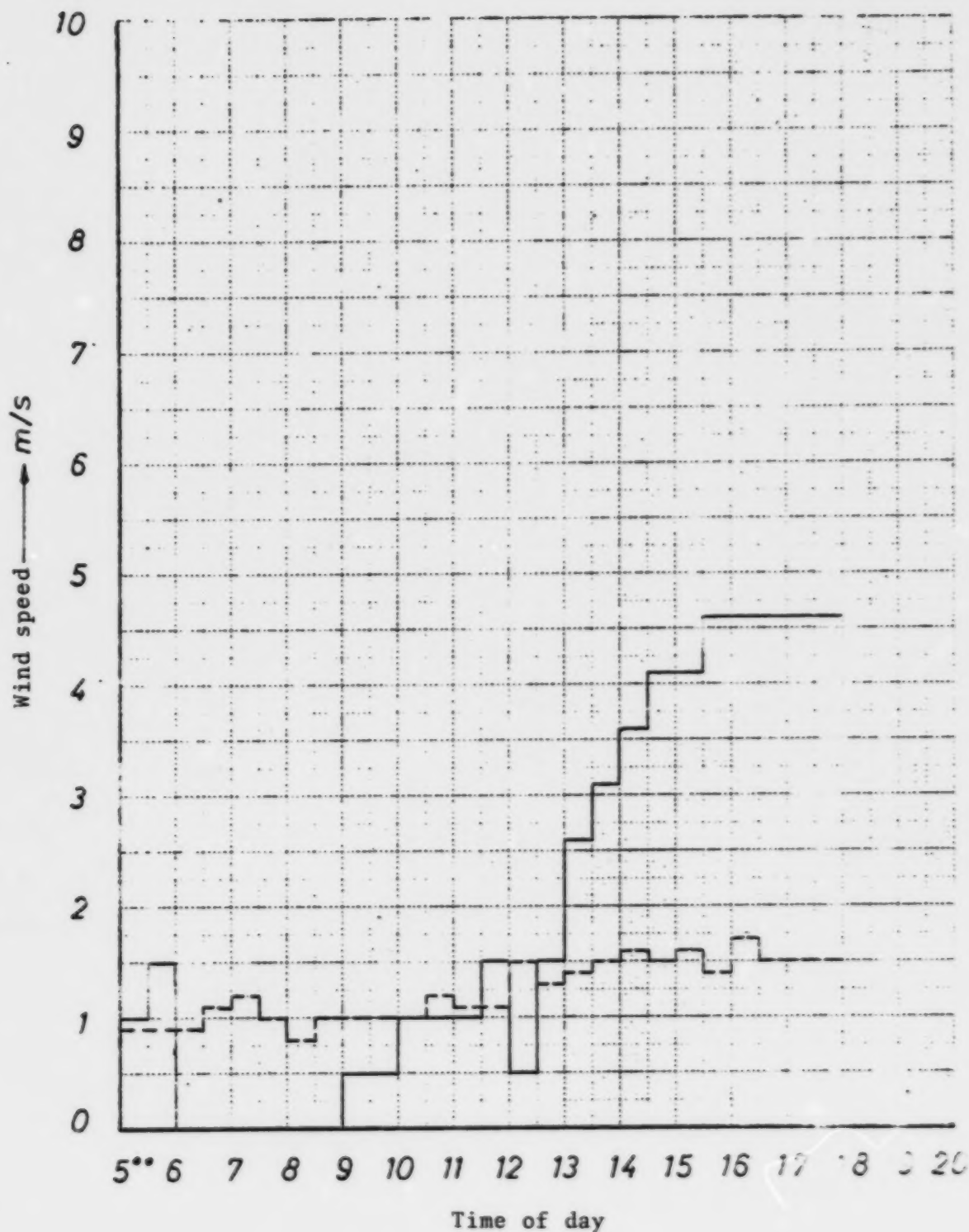
|                         |                                                                                      |                                                                                 |                   |
|-------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------|
| <b>TÜV</b><br>Rheinland | Daily lines for variations in wind direction and CO concentration at various heights | Immissions,<br>city of Cologne<br>Measuring site: 6 4<br>Date: July 13-14, 1972 | Sheet 4<br>out of |
|-------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------|



TÜV  
Rheinland

Daily lines for the course of the global and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 6  
Date: July 13, 1972

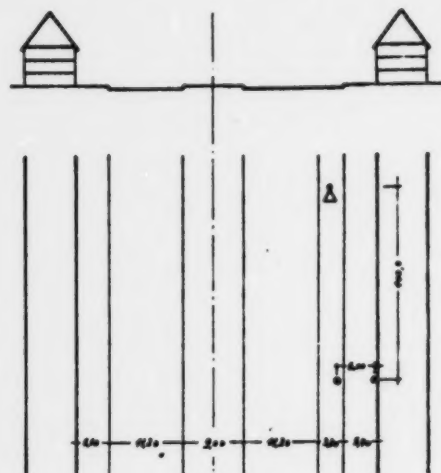
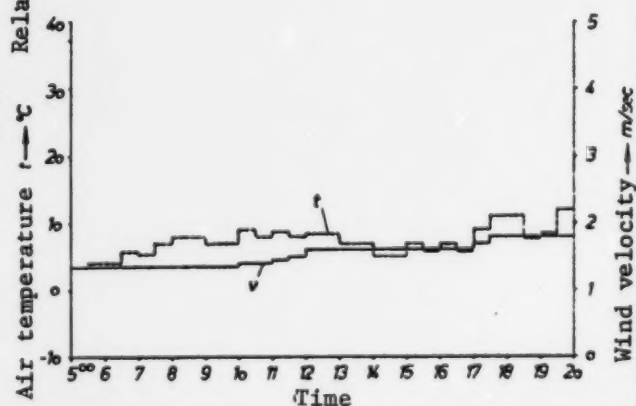
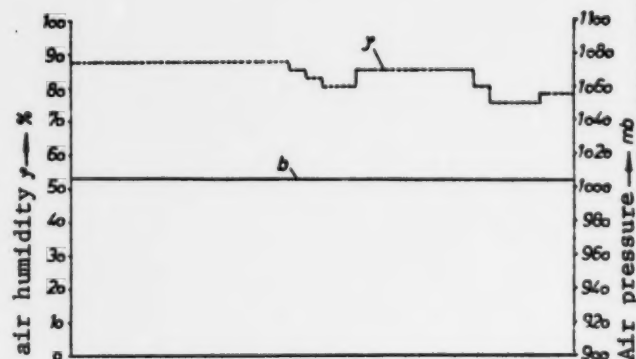
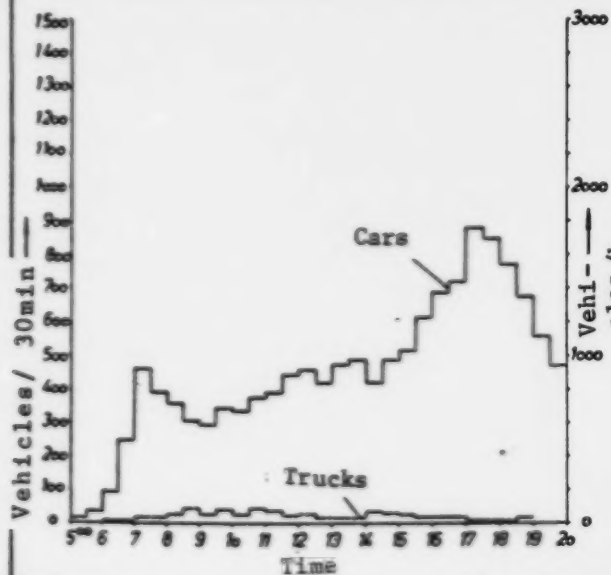


TÜV  
Rheinland

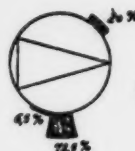
Daily lines for the course of the global  
and local wind speed.

Emissions,  
city of Cologne  
Measuring site: 6  
Date: July 14, 1972





Measurement 0.75 m  
sight height



Wind Frequency

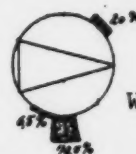
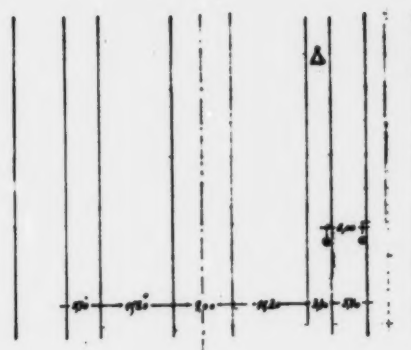
Wind direction relative to street axis



TÜV  
Rheinland

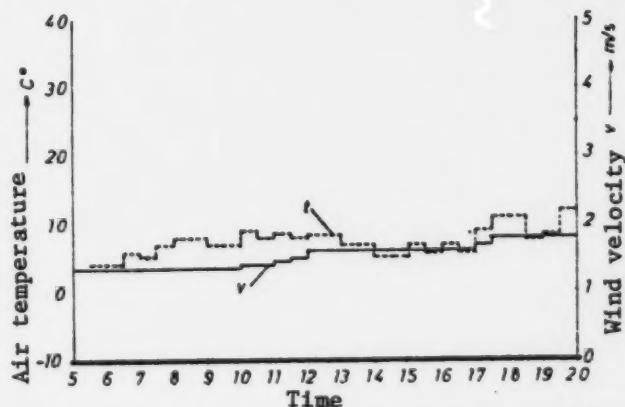
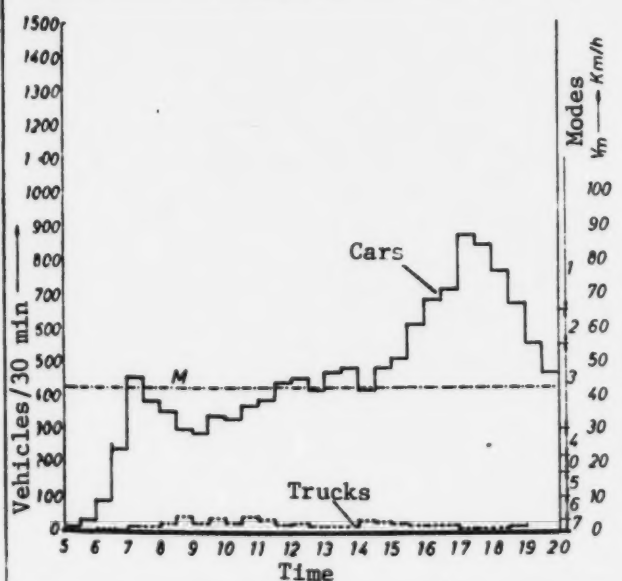
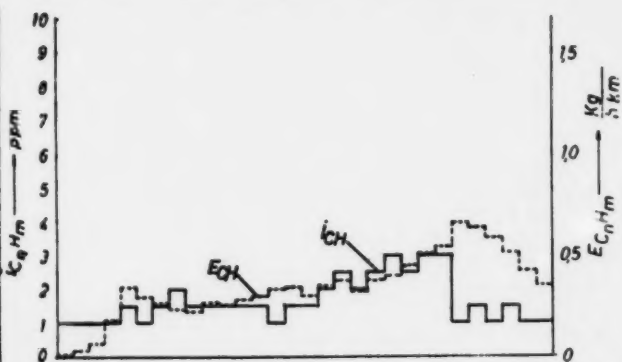
Daily lines for the course of traffic  
density, exhaust gas components and  
meteorological variables

Immissions,  
city of Cologne  
Measuring site: 7  
Date: Dec. 27, 1971



Wind frequency

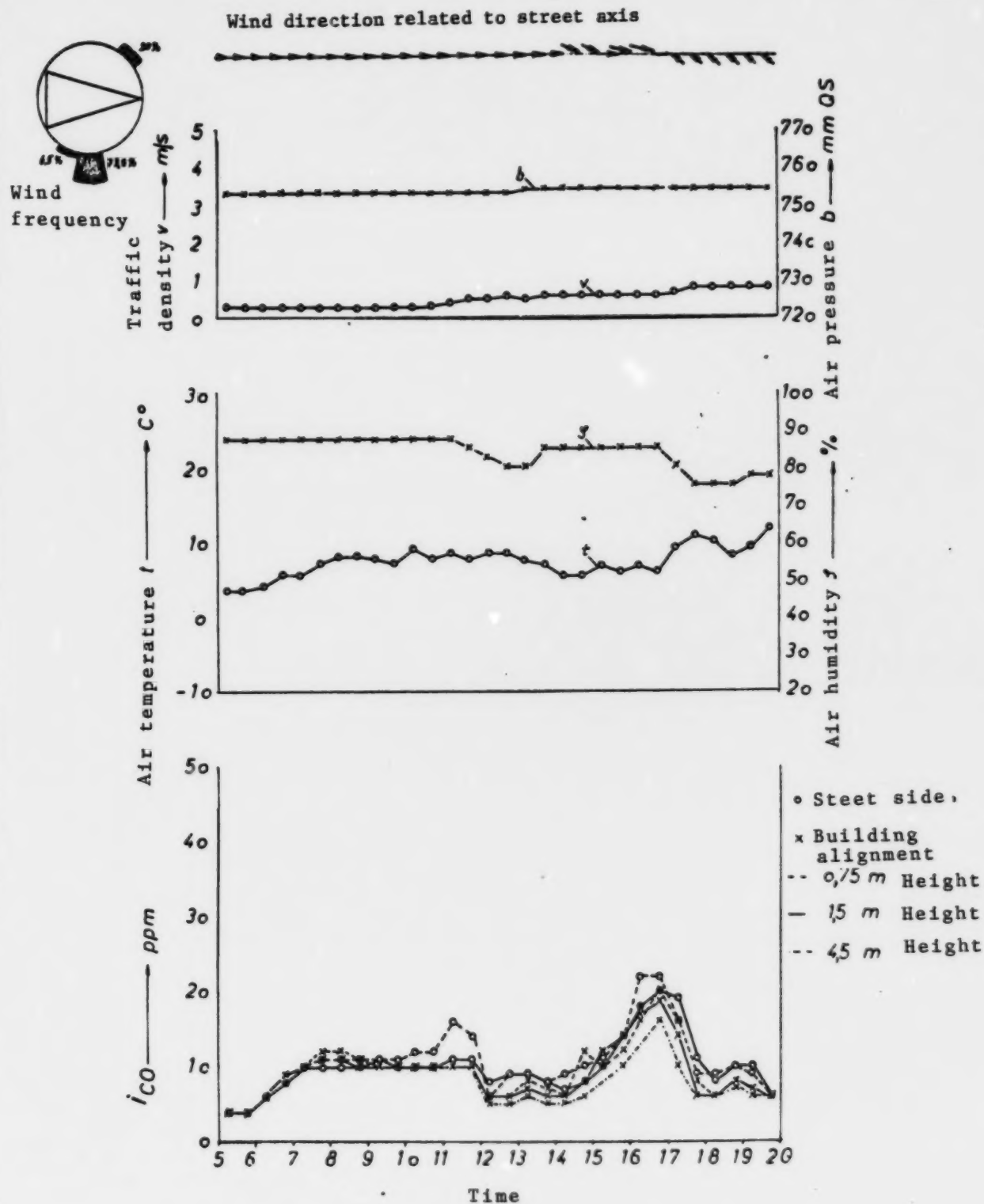
Wind direction relative to street axis



TUV  
Rheinland

Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

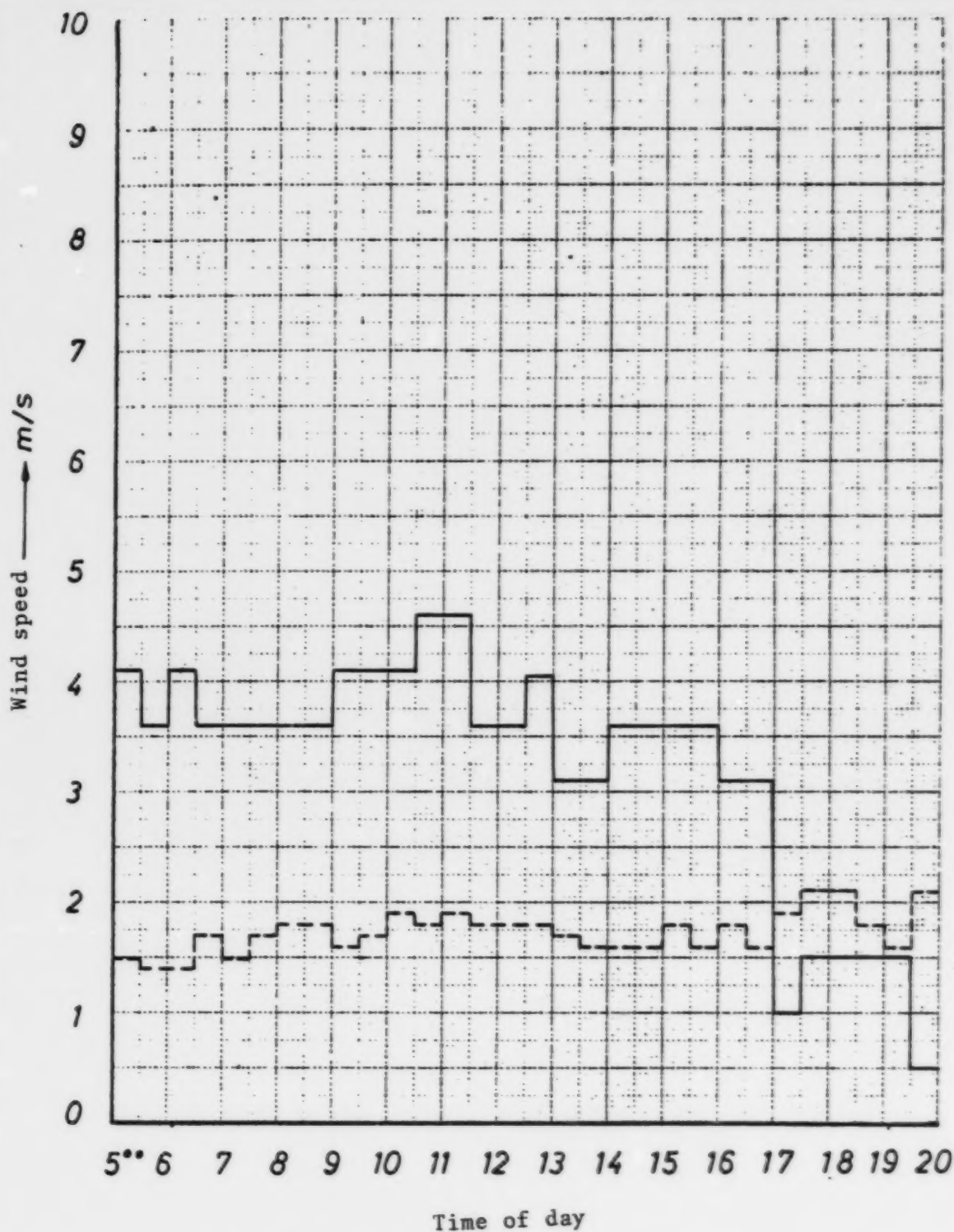
Immissions,  
city of Cologne  
Measuring site: 7  
Date: Dec. 27, 1971



TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 7  
Date: Dec. 27, 1971



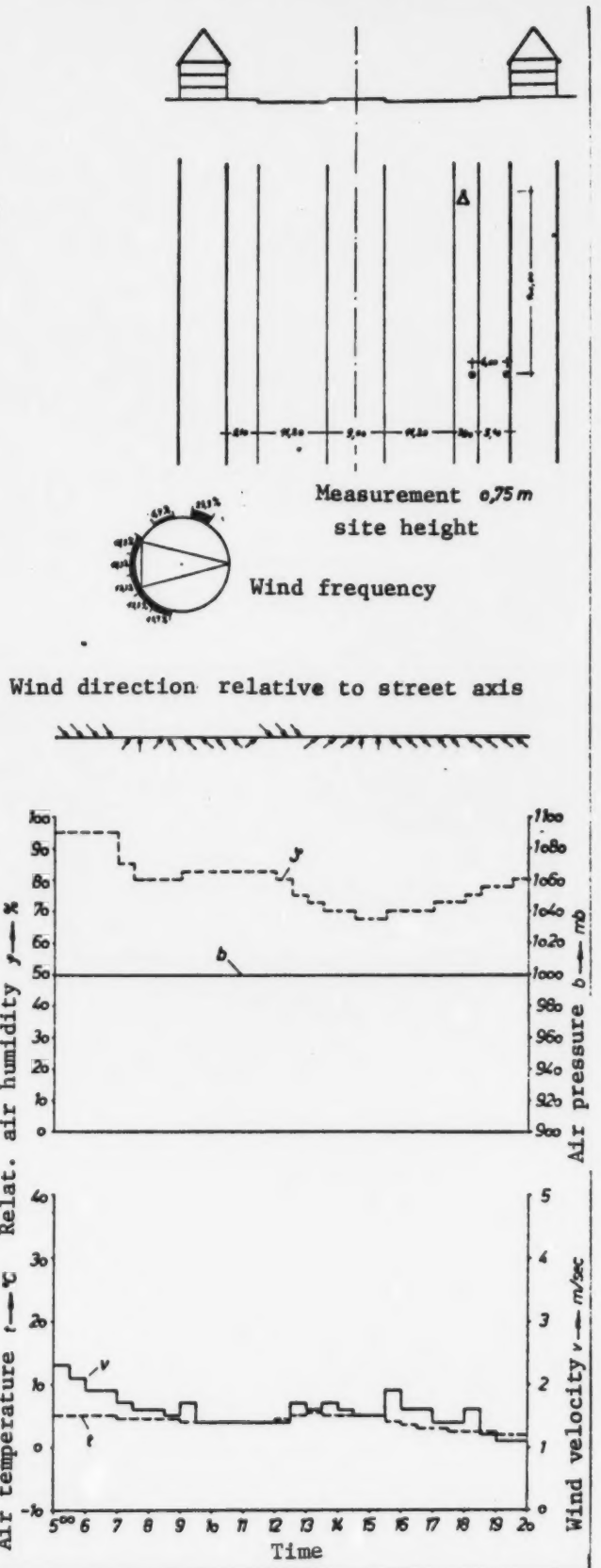
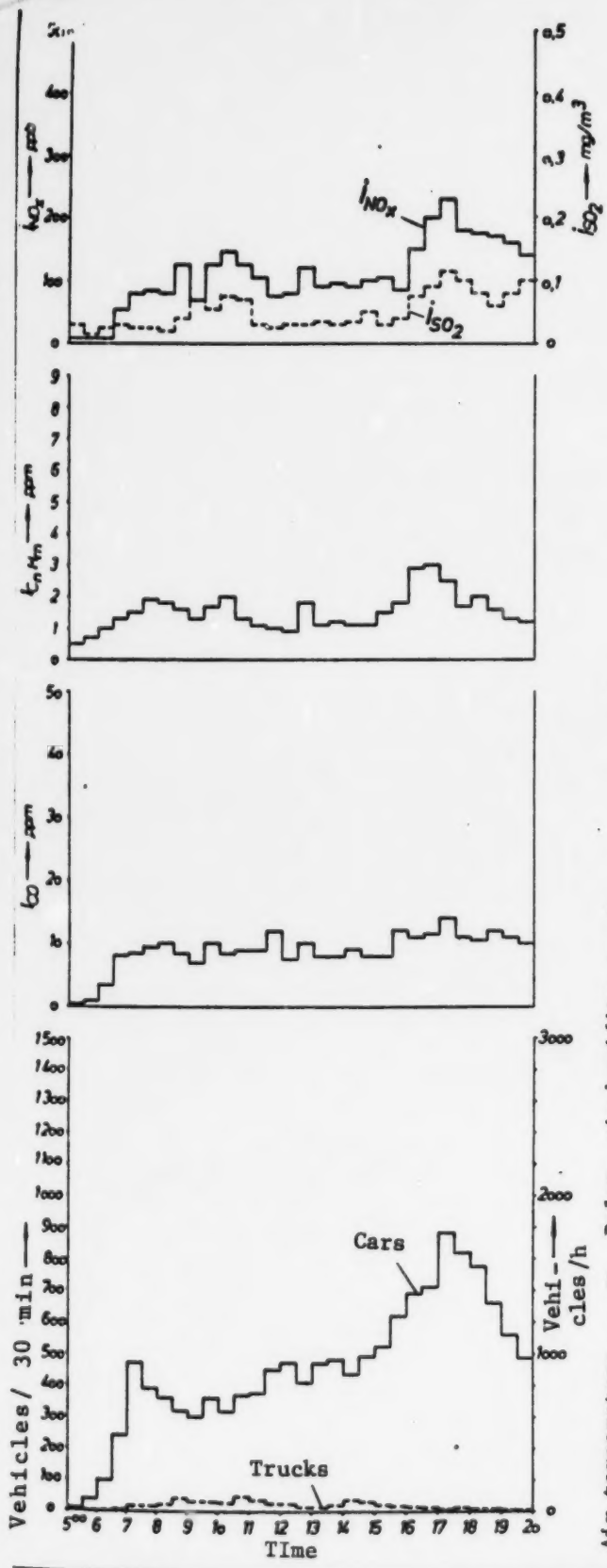
— Global wind speed  
 ---- Local wind speed

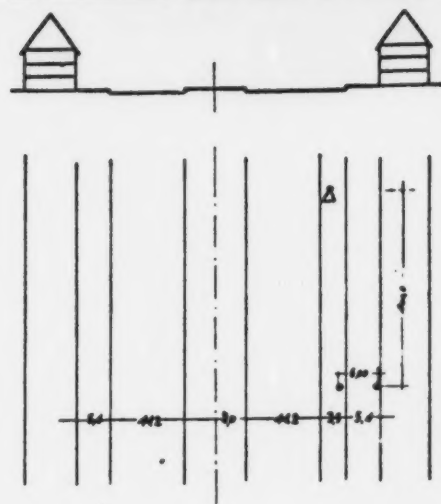
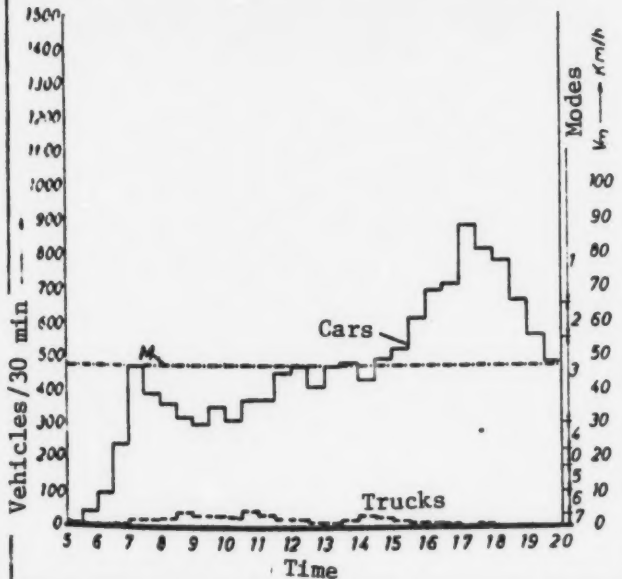
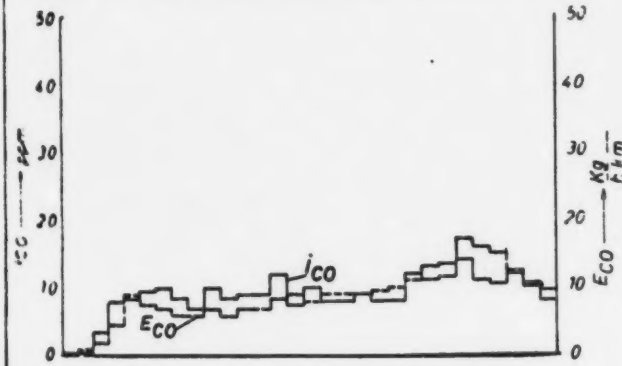
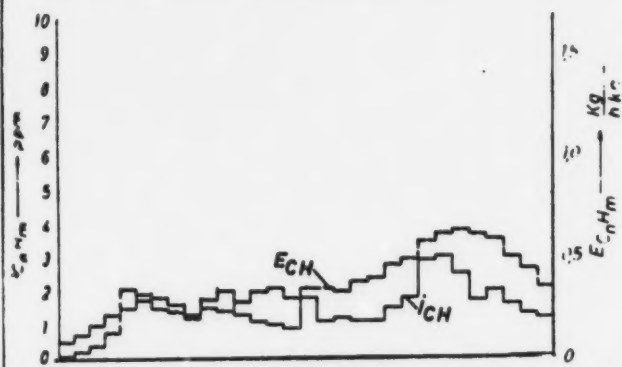
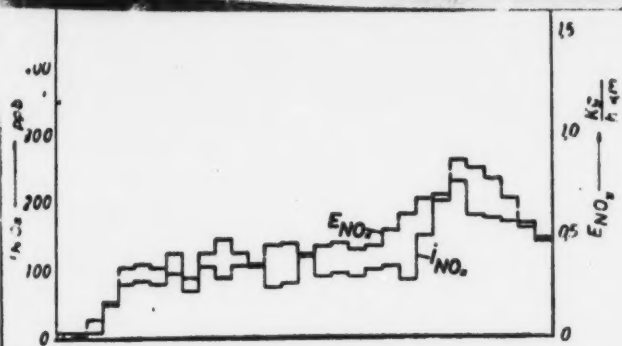
TÜV  
 Rheinland

Daily lines for the course of the global and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 7  
 Date: Dec. 27, 1971

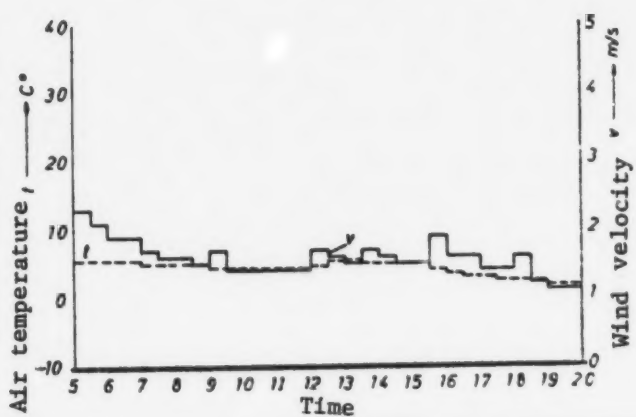
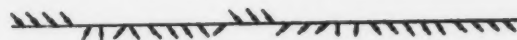






Wind frequency

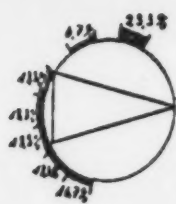
Wind direction relative to street axis



TÜV  
Rheinland

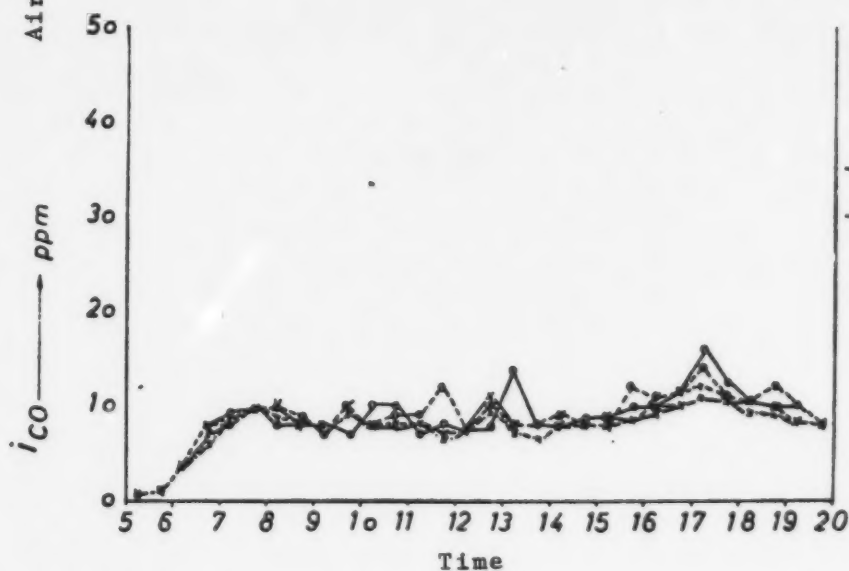
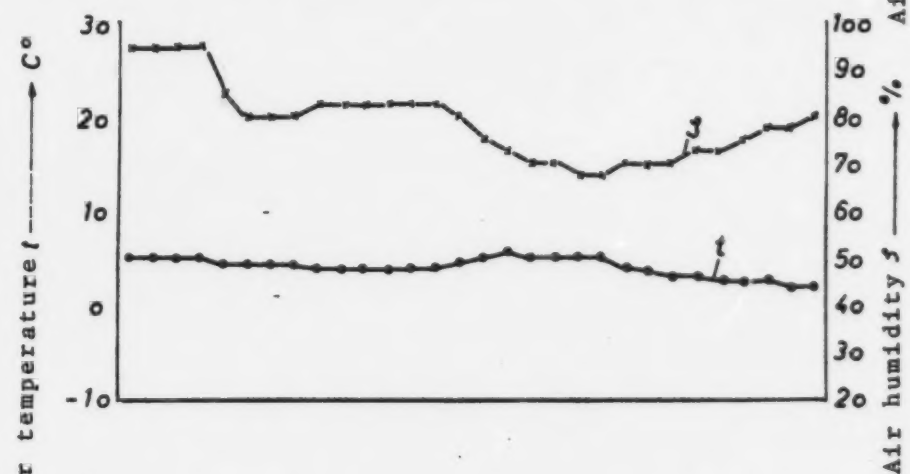
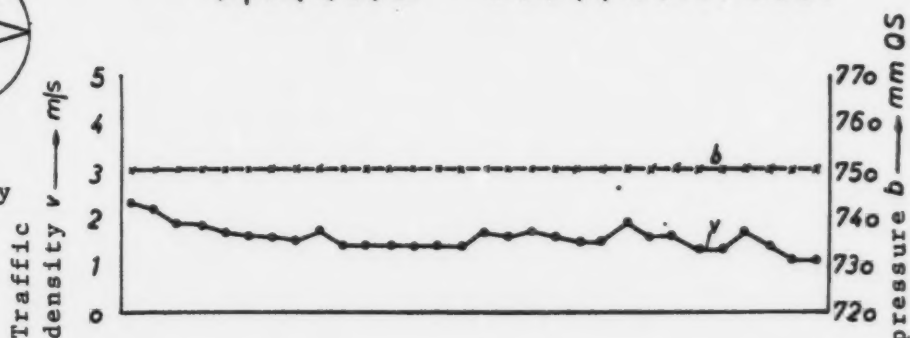
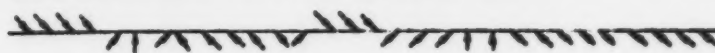
Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 7  
Date: Dec. 28, 1971



frequency

Wind direction related to street axis

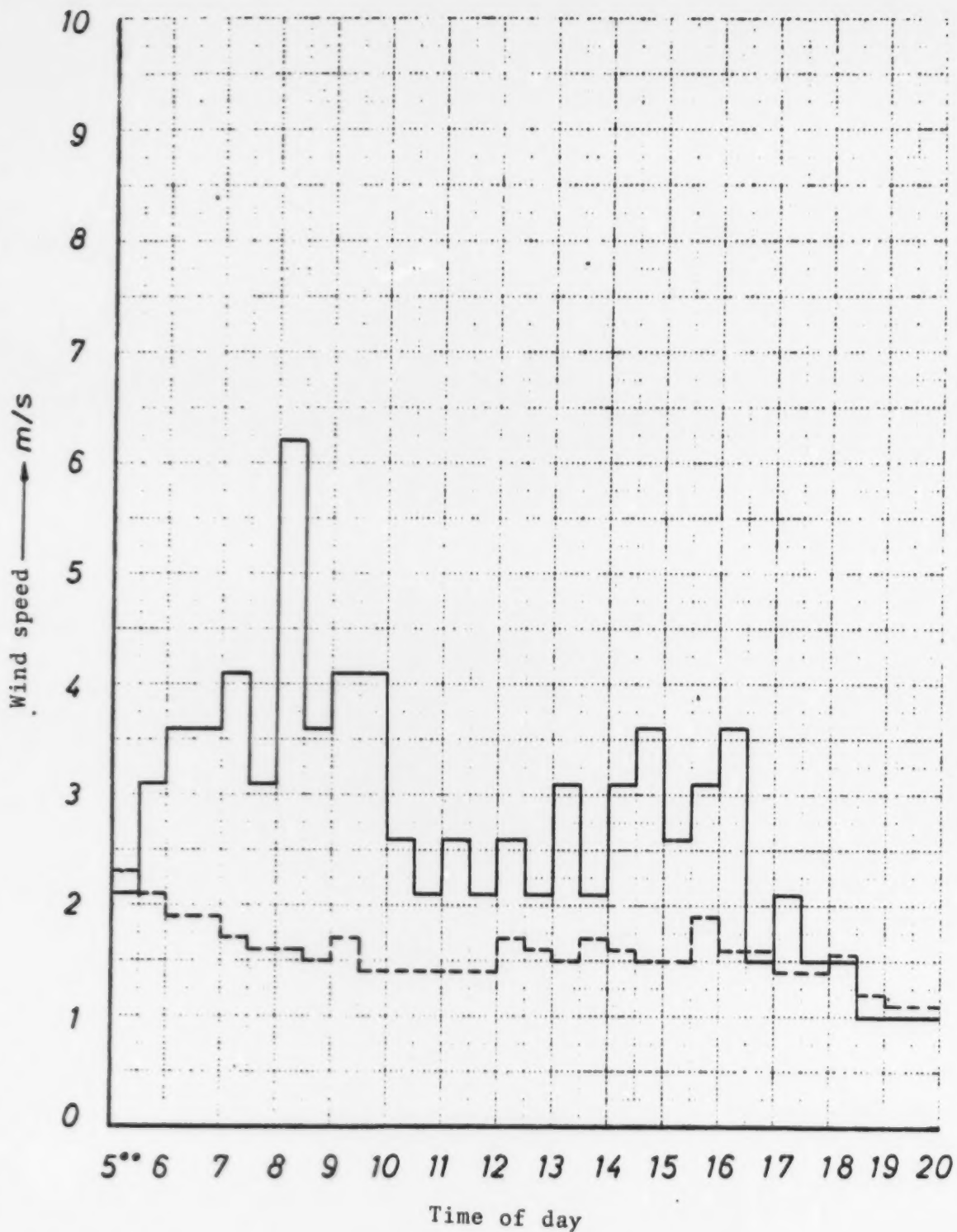


- Street side
- x Building alignment
- 0,75 m Height
- 1,5 m Height
- - 4,5 m Height

TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 7  
Date: Dec. 28, 1971



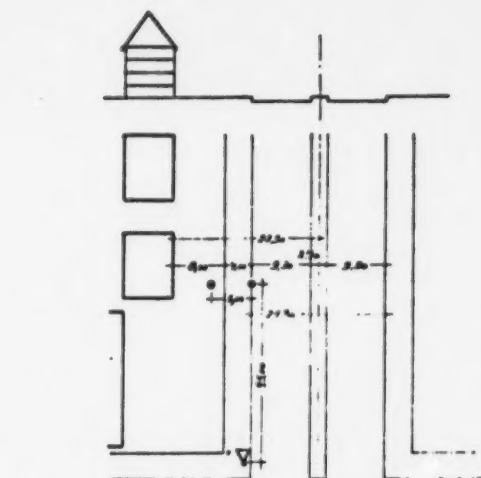
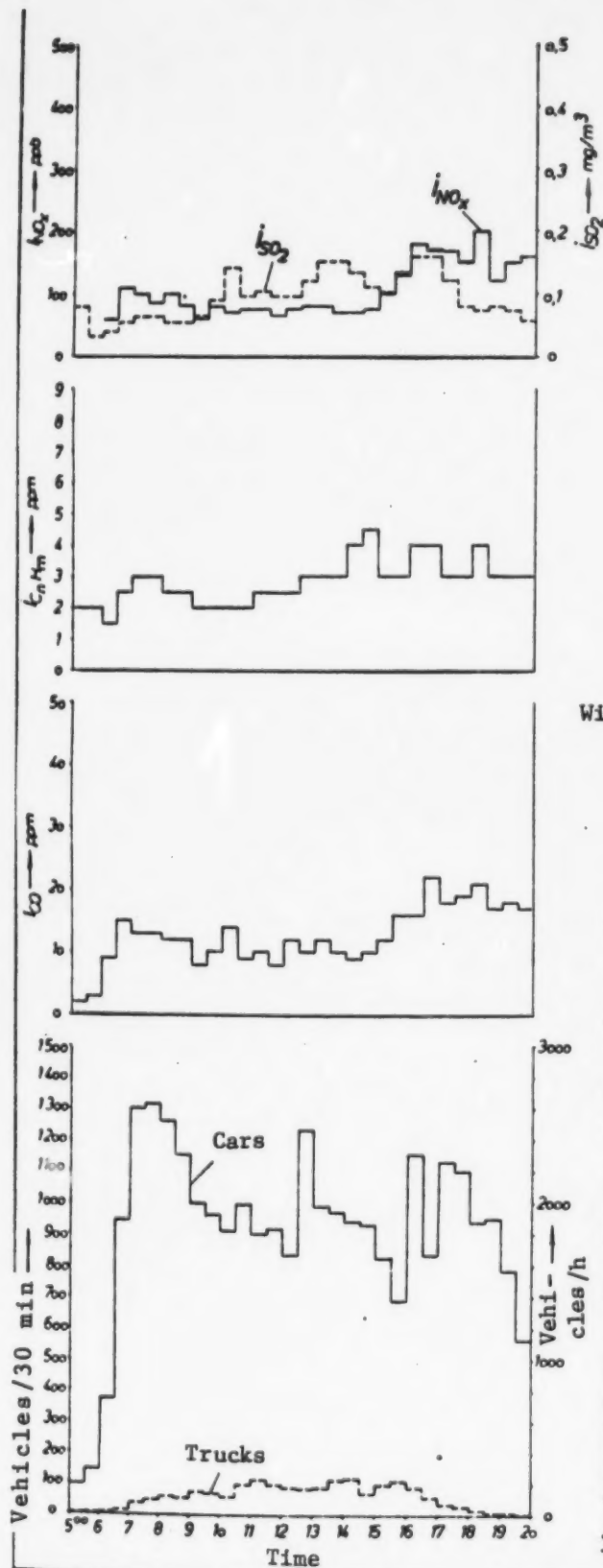
— Global wind speed  
 ---- Local wind speed

TÜV  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 7  
 Date: Dec. 28, 1971



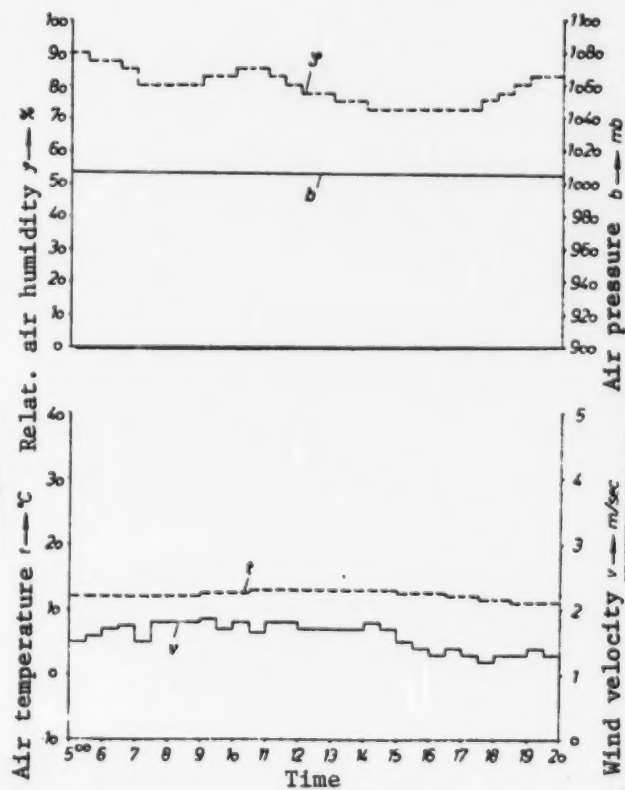
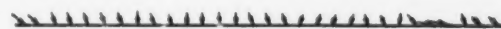


Measurement 0,75 m  
site height



Wind frequency

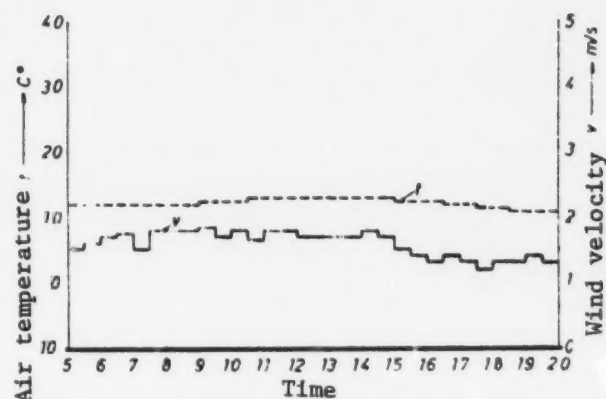
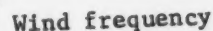
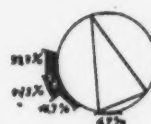
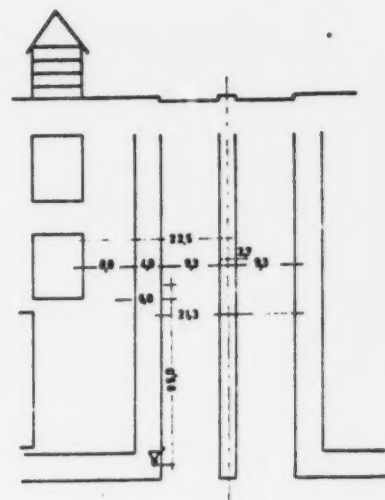
Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

Immissions,  
city of Cologne  
Measuring site: 8  
Date: Dec. 22, 1971



**TÜV**  
Süd

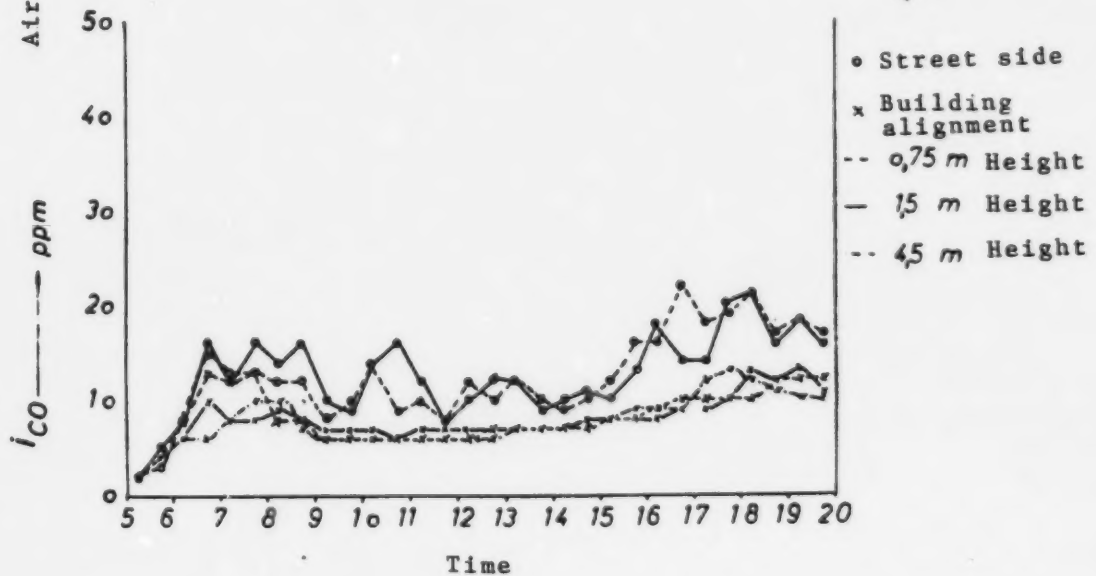
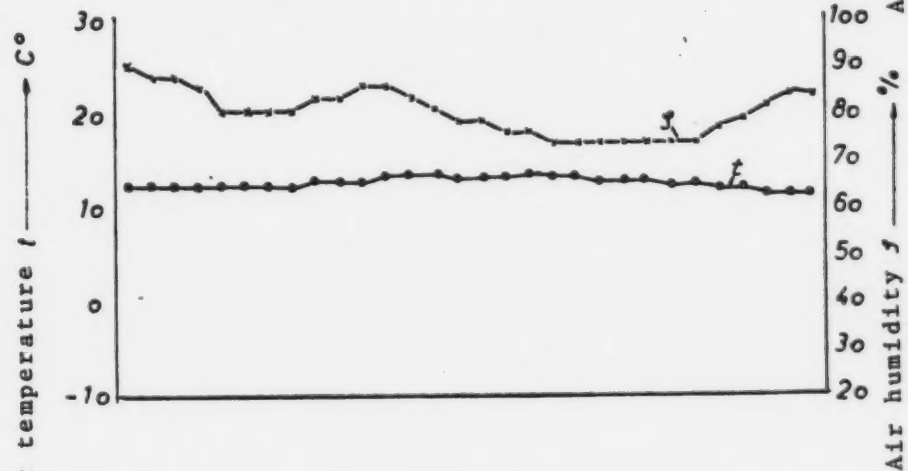
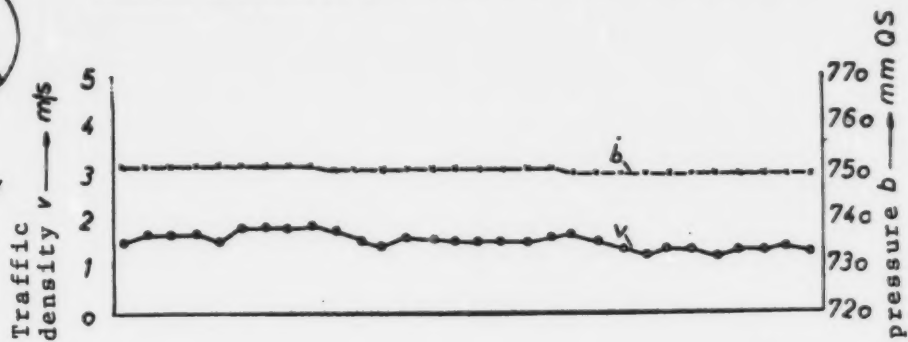
Daily lines for traffic density, exhaust  
gas components (immission, emission) and  
meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 8  
Date: Dec. 22, 1971

# Wind direction related to street axis



Wind frequency

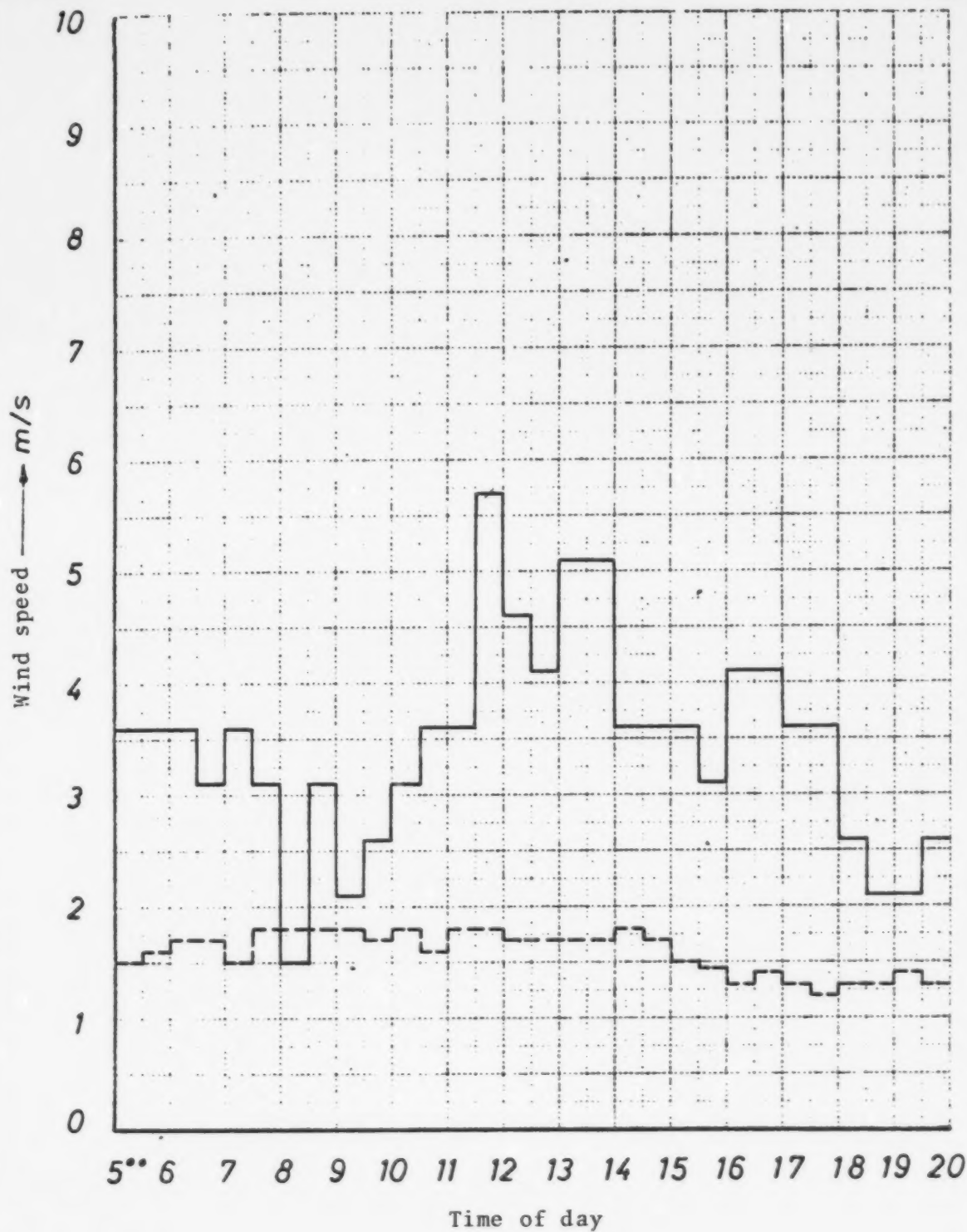


TÜV

BERLIN

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 8  
Date: Dec. 22, 1971



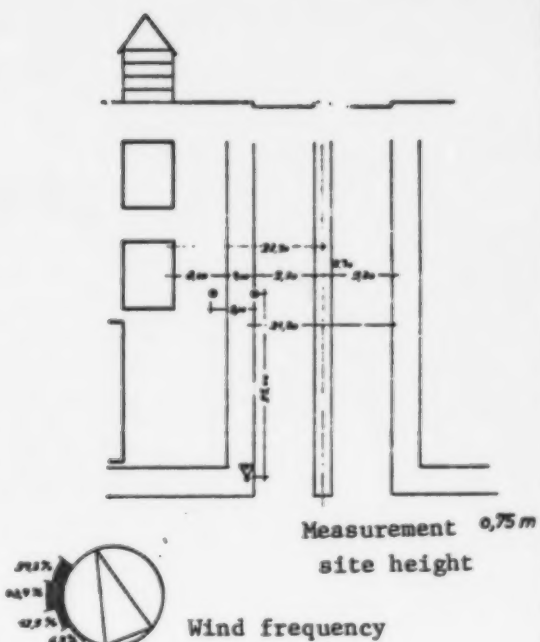
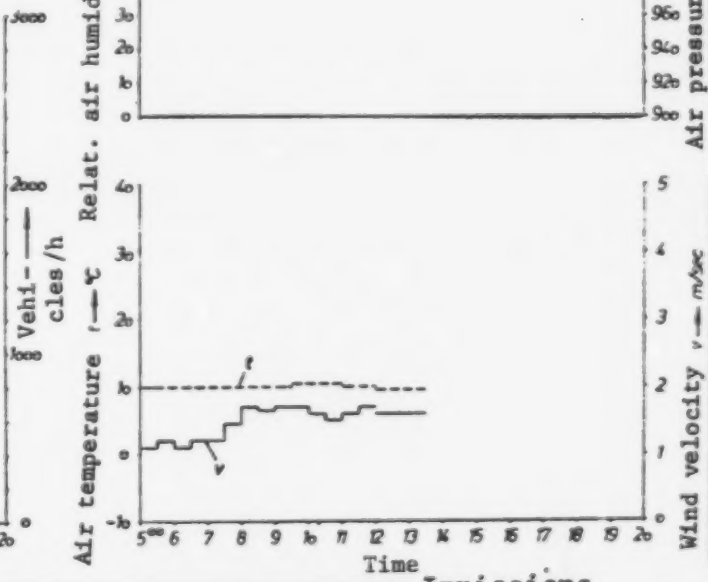
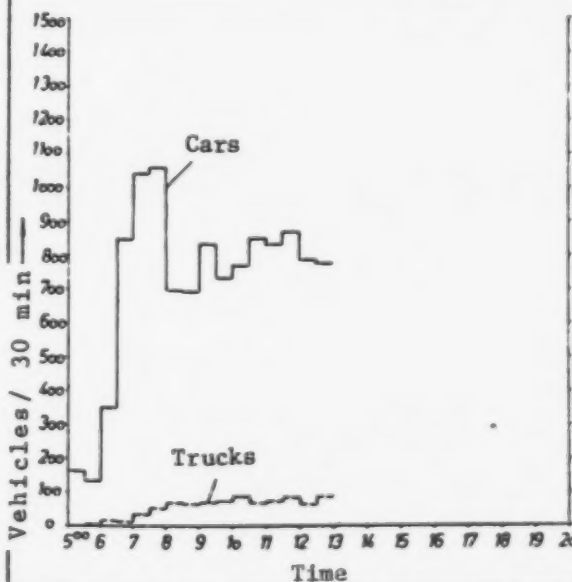
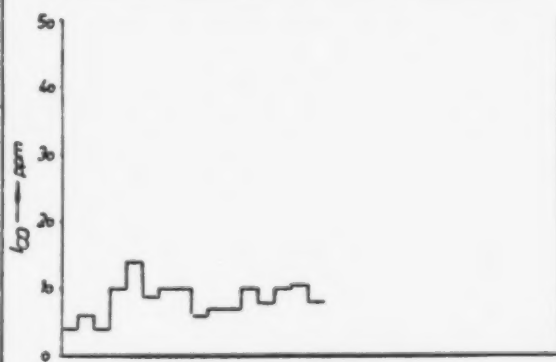
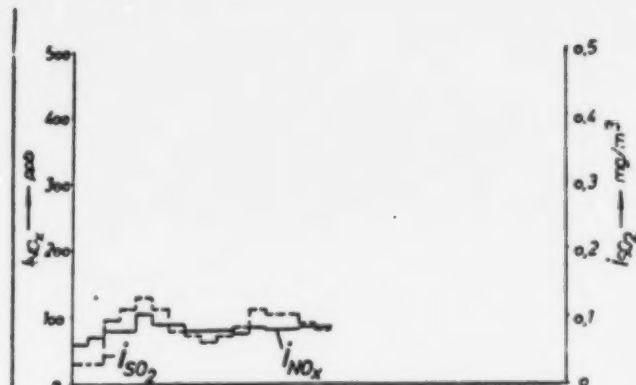
— Global wind speed  
 ---- Local wind speed

TÜV  
 RHEINLAND

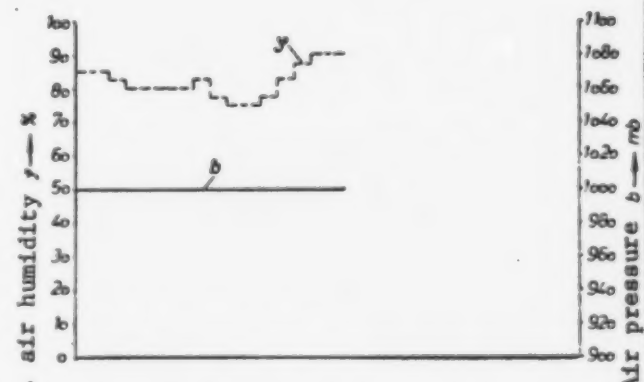
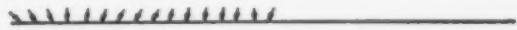
Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 8  
 Date: Dec. 22, 1971





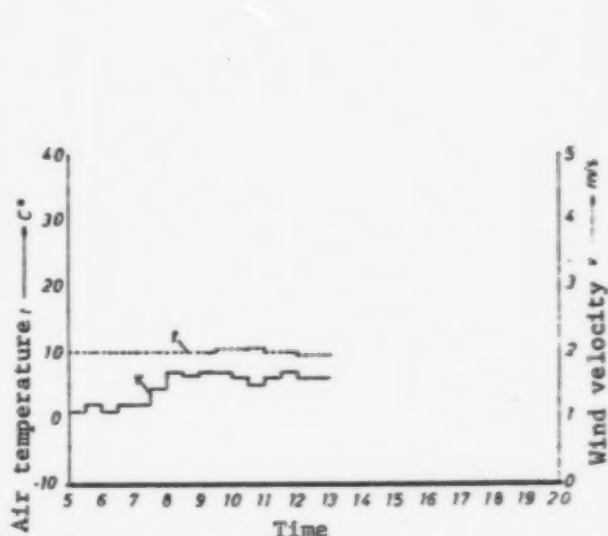
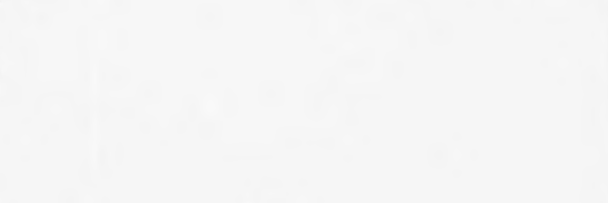
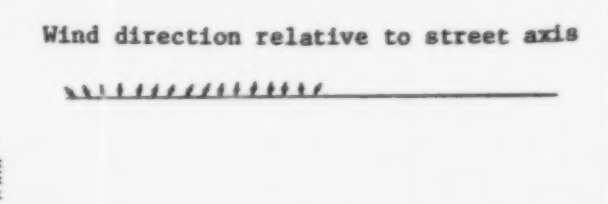
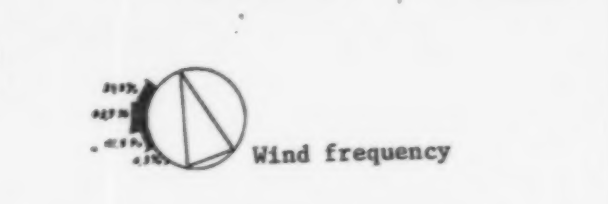
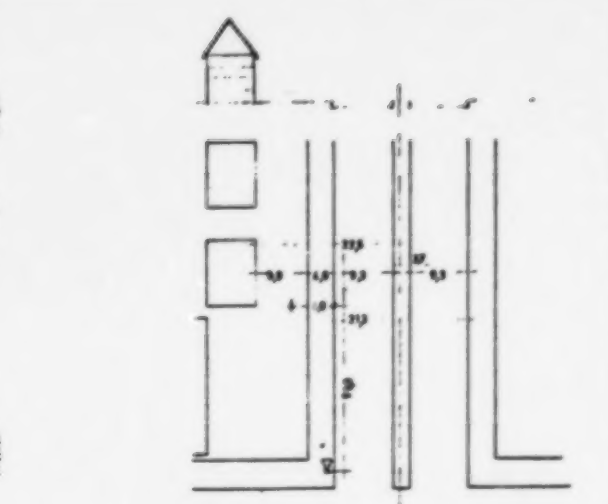
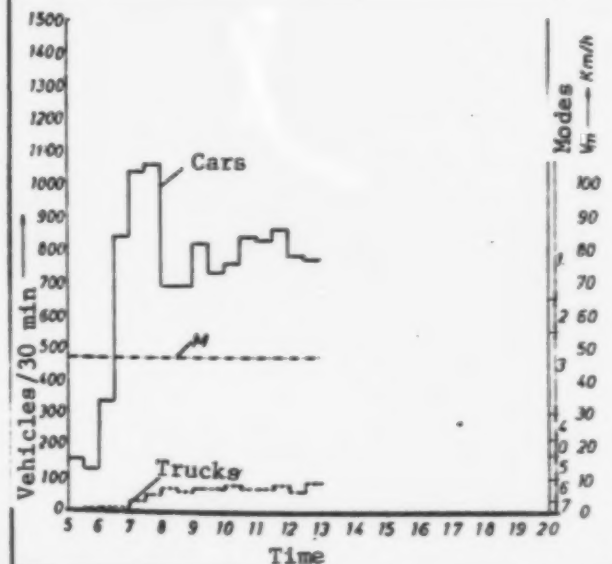
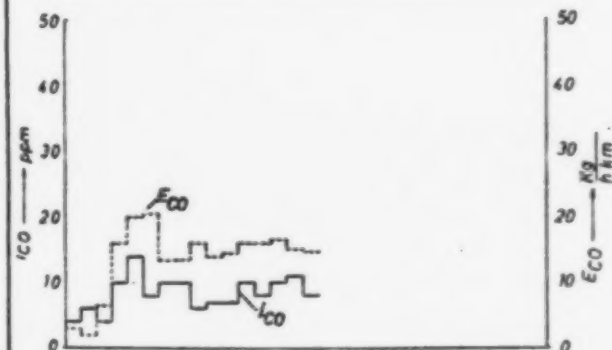
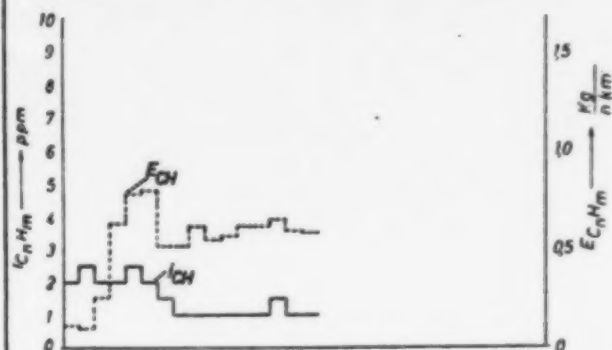
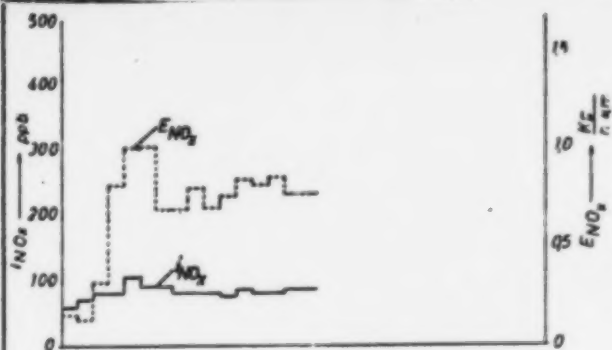
Wind direction relative to street axis



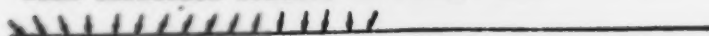
TÜV  
Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

Immissions,  
city of Cologne  
Measuring site: 8  
Date: Dec. 23, 1971

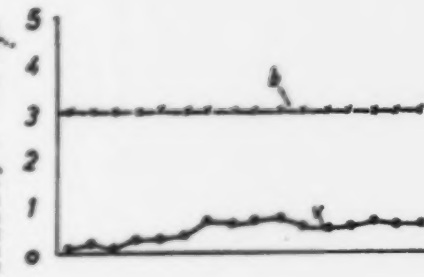


Wind direction related to street axis



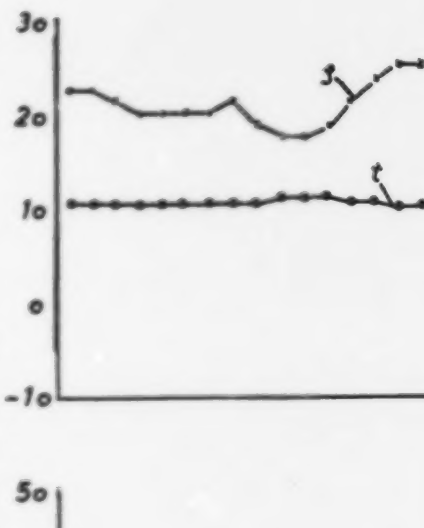
Wind frequency

Traffic density  $v$   $\rightarrow$  mm QS



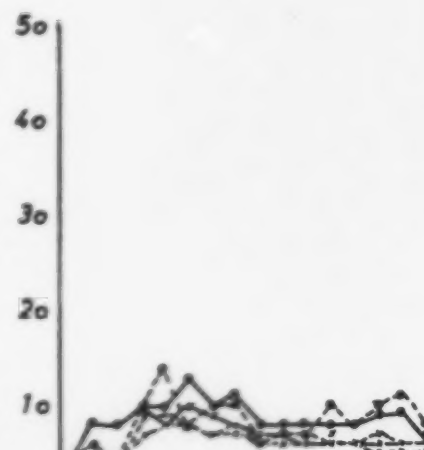
770  
760  
750  
740  
730  
720  
Air pressure  $b$   $\rightarrow$  mm QS

30  
20  
10  
0  
-10  
Air temperature  $t$   $\rightarrow$  C°



100  
90  
80  
70  
60  
50  
40  
30  
20  
Air humidity  $f$   $\rightarrow$  %

50  
40  
30  
20  
10  
0  
 $i_{CO}$   $\rightarrow$  ppm



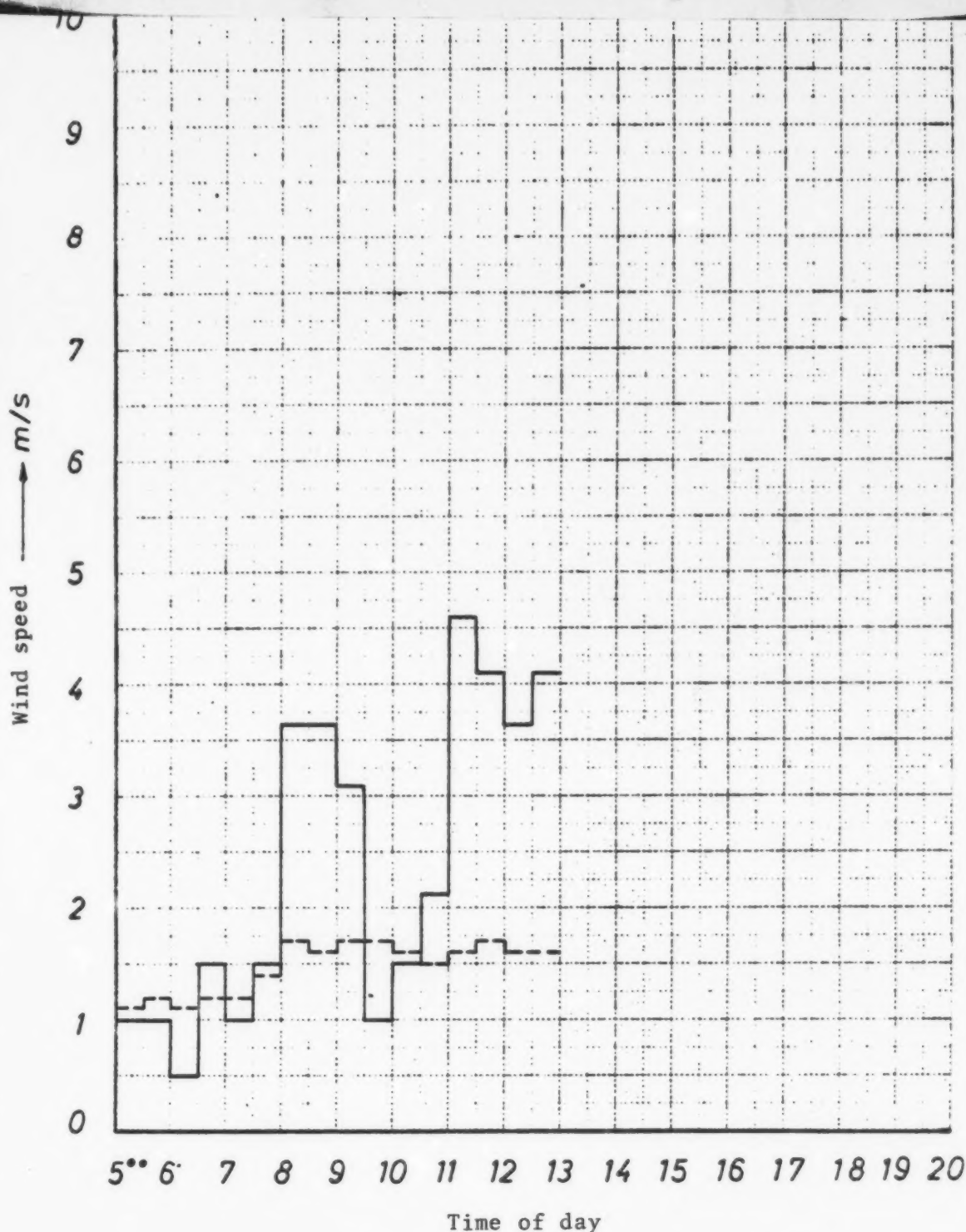
- Street side
- x Building alignment
- 0,75 m Height
- 1,5 m Height
- 4,5 m Height

Time

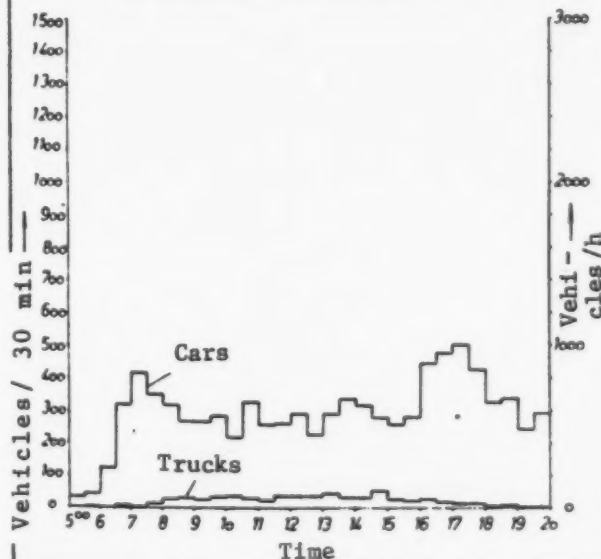
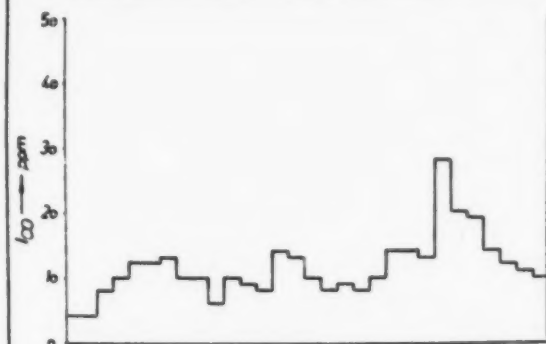
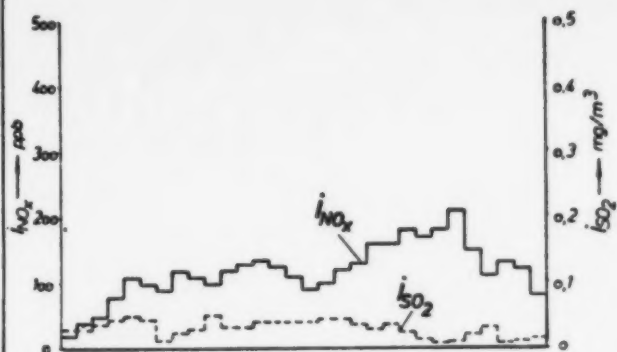
TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

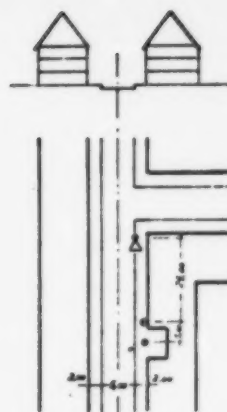
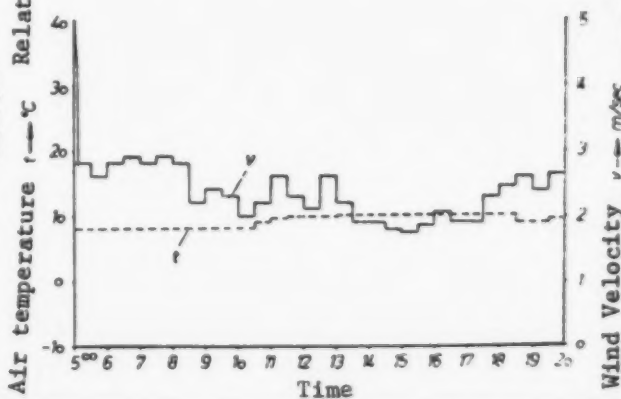
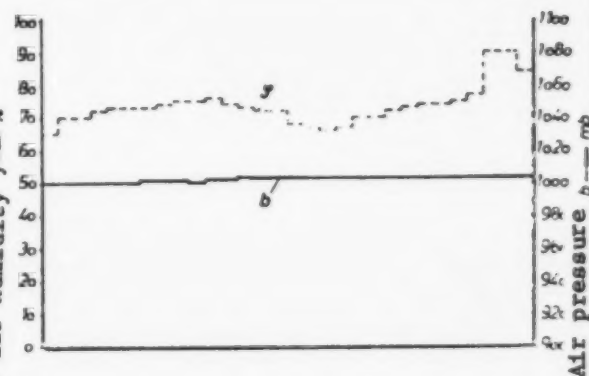
Immissions,  
city of Cologne  
Measuring site: 8  
Date: Dec. 23, 1971







Wind direction relative to street axis



Measurement 0.75 m site height



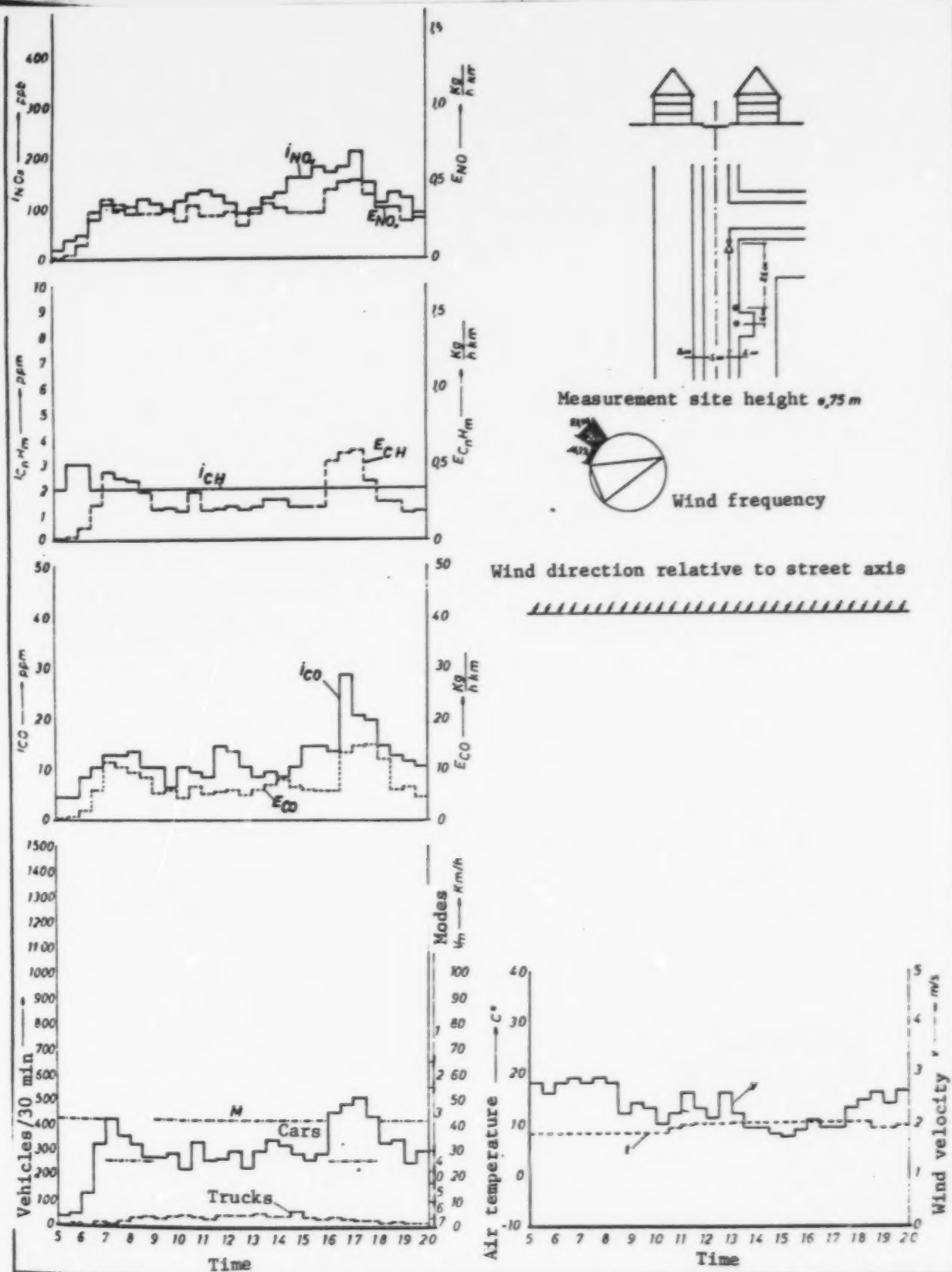
Wind frequency

TÜV  
Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

Immissions,  
city of Cologne  
Measuring site: 9

Date: Dec. 20, 1971



TÜV  
Rheinland

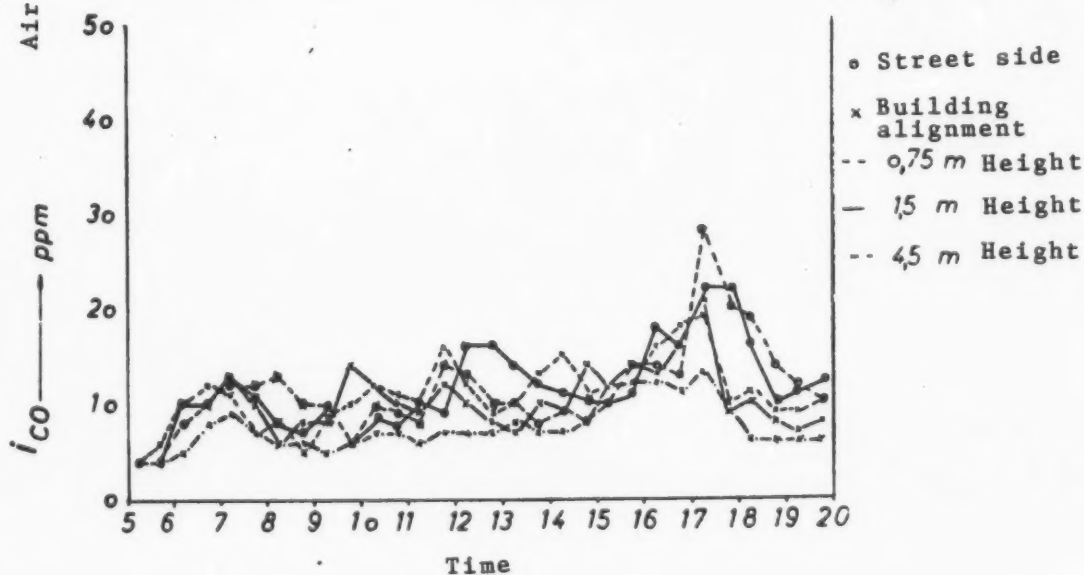
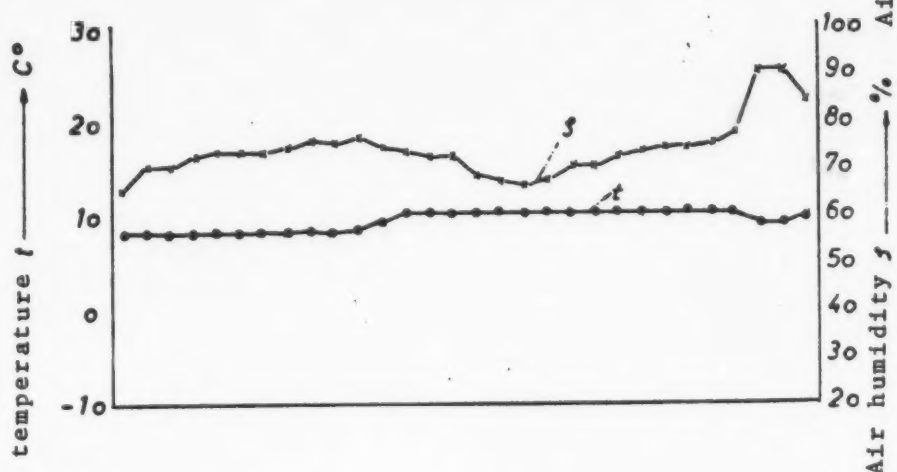
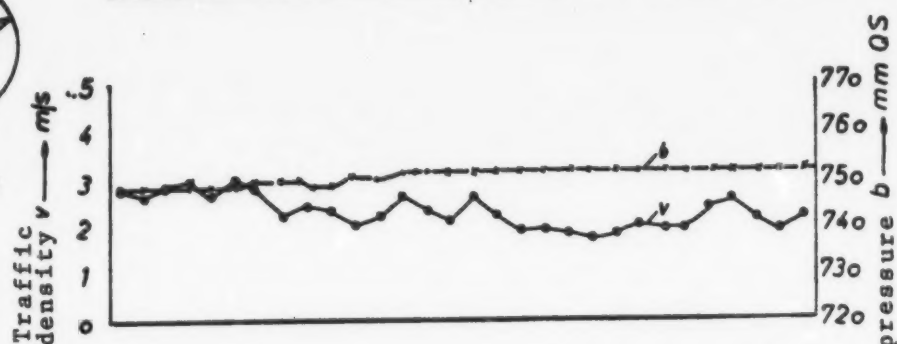
Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 9  
Date: Dec. 20, 1971



Wind frequency

Wind direction related to street axis



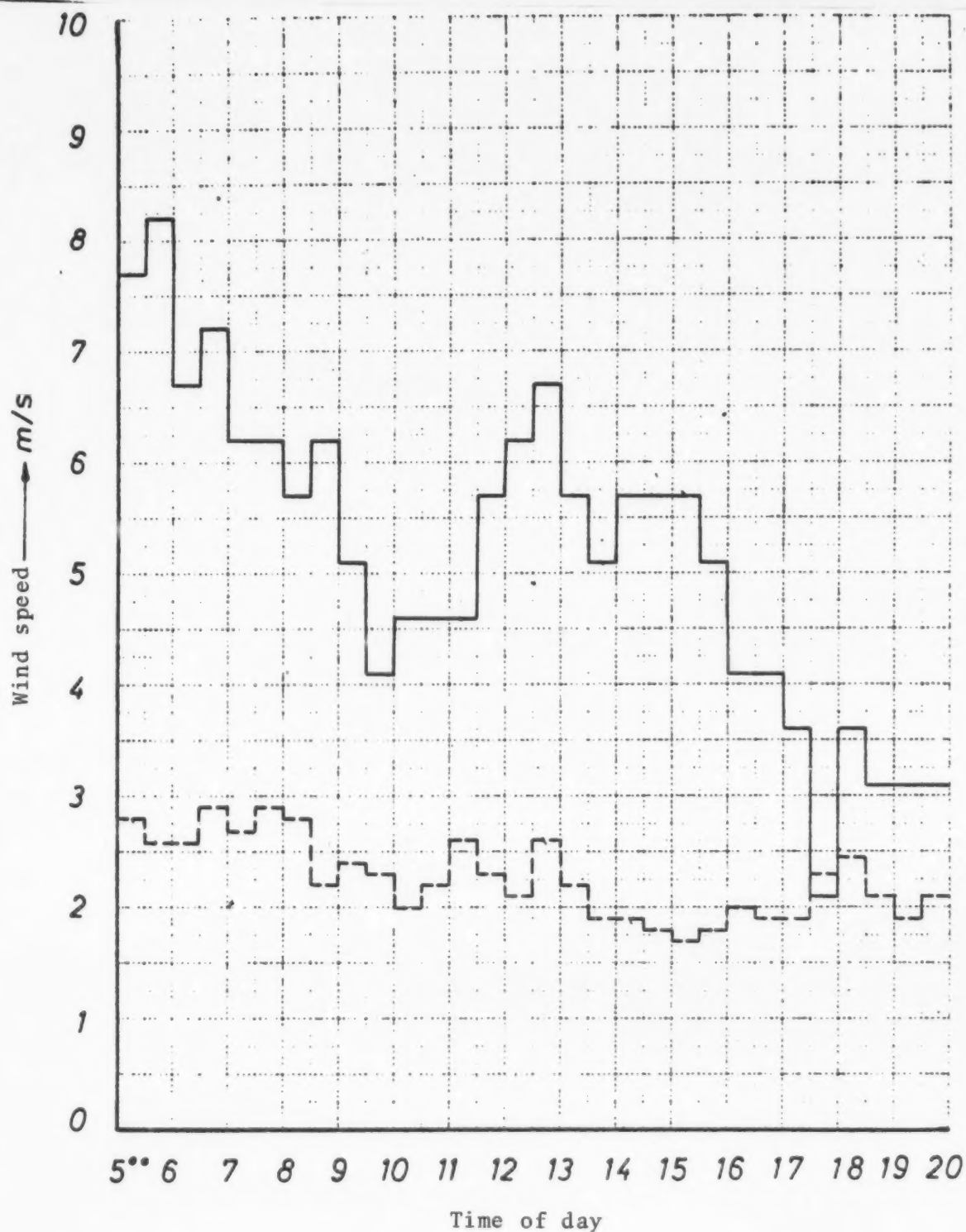
TÜV

Technische Universität

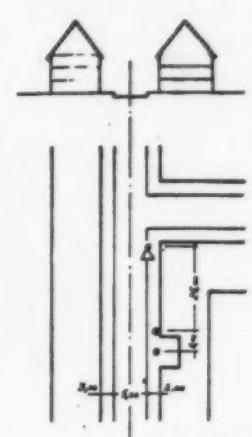
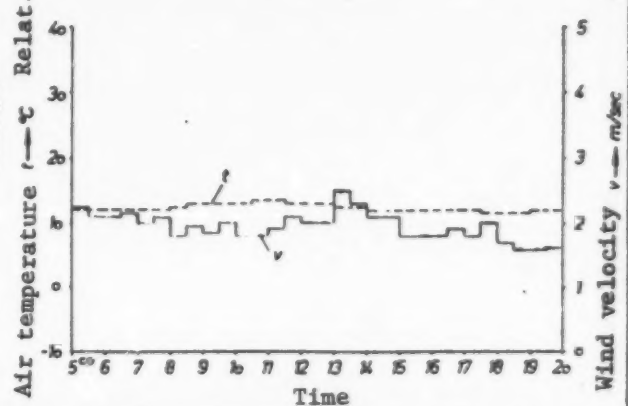
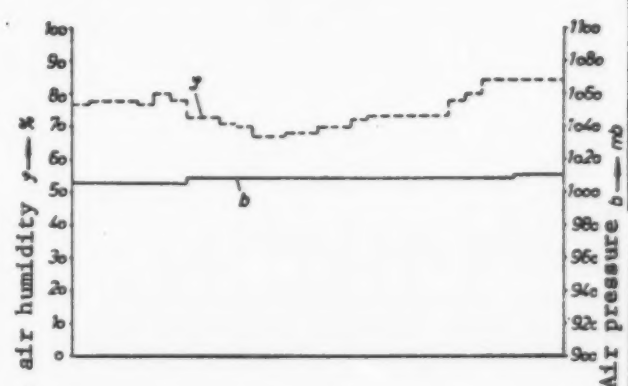
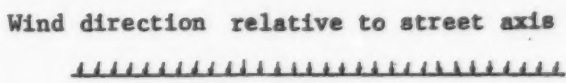
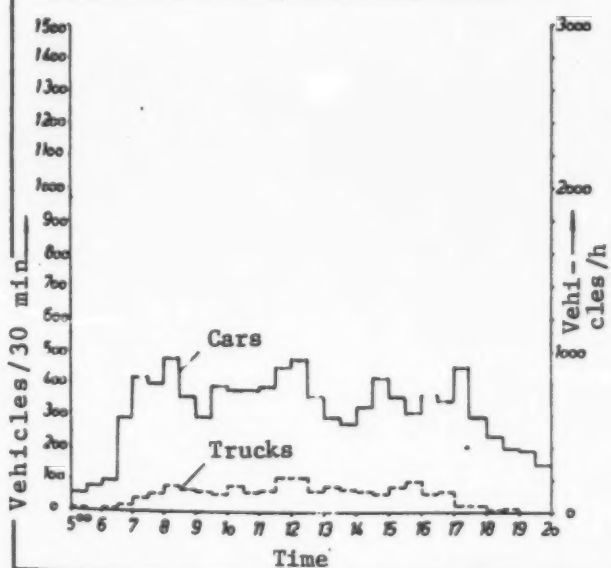
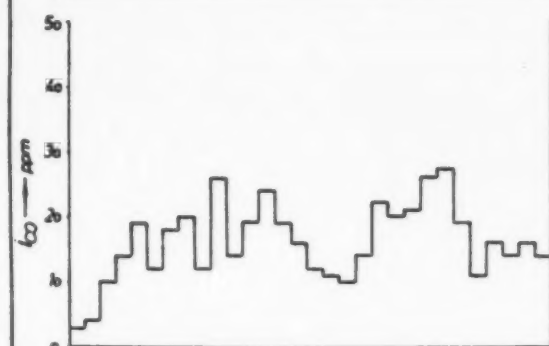
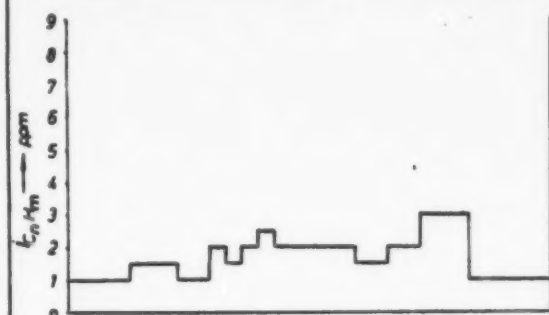
Daily lines of CO concentration at various altitudes and meteorological variables.

Emissions, city of Cologne  
Measuring site:

Date: Dec. 20, 1971







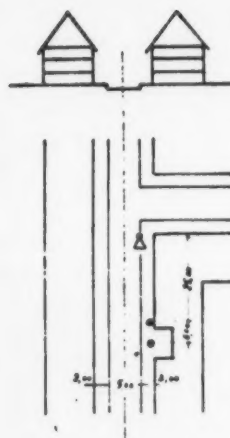
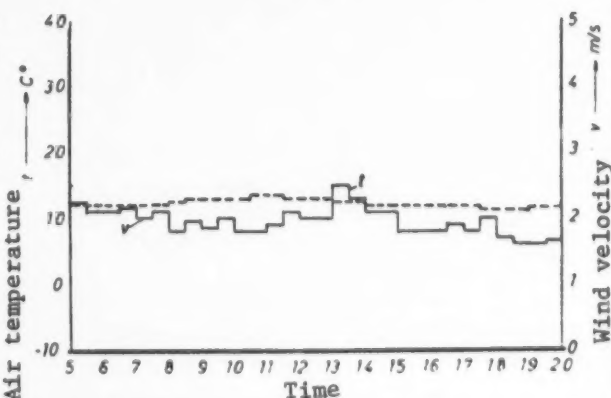
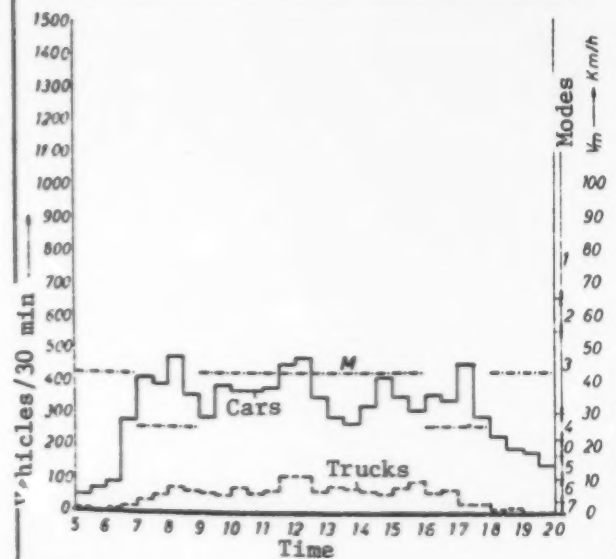
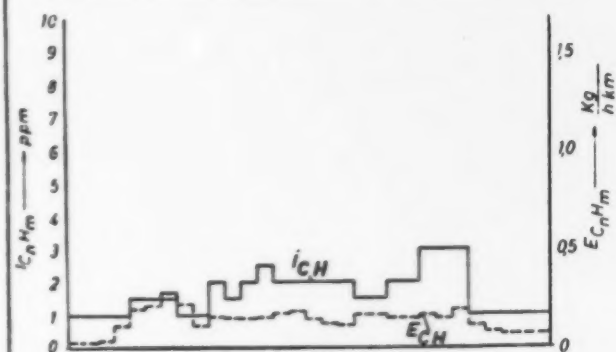
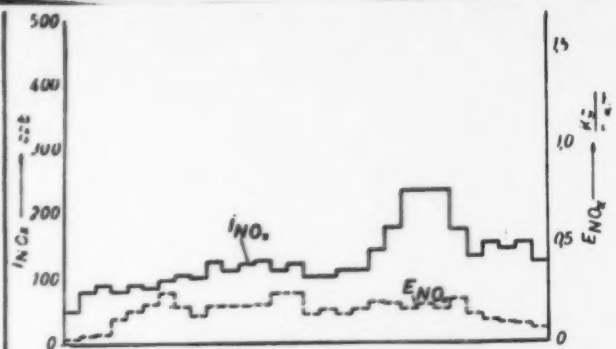
Measurement 0.75 m  
site height

Wind frequency

TÜV  
Rheinland

Daily lines for the course of traffic  
density, exhaust gas components and  
meteorological variables

Immissions,  
city of Cologne  
Measuring site: 9  
Date: Dec. 21, 1971



Wind frequency

Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

Immissions,  
city of Cologne  
Measuring site:

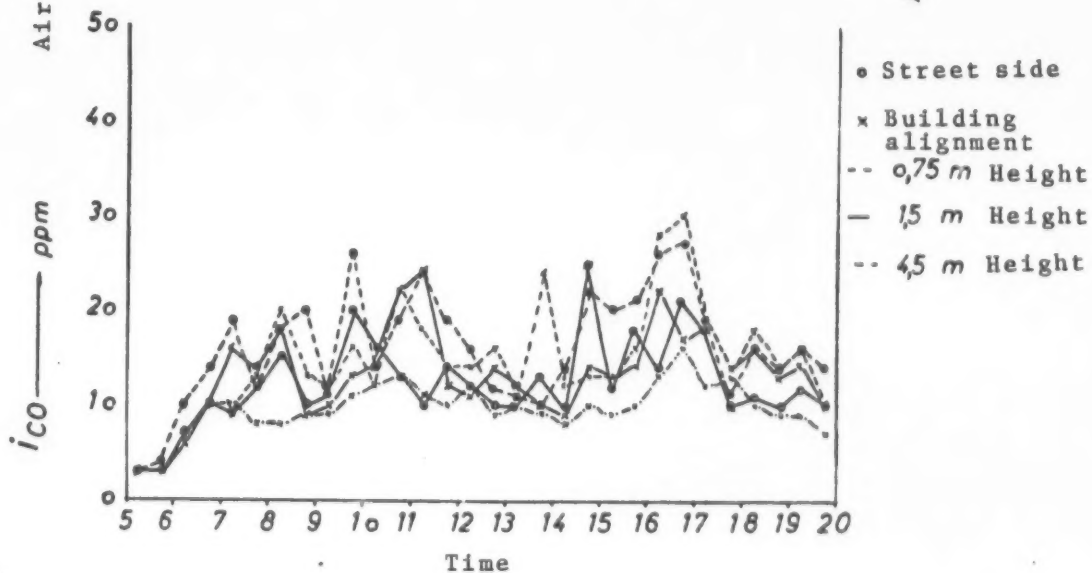
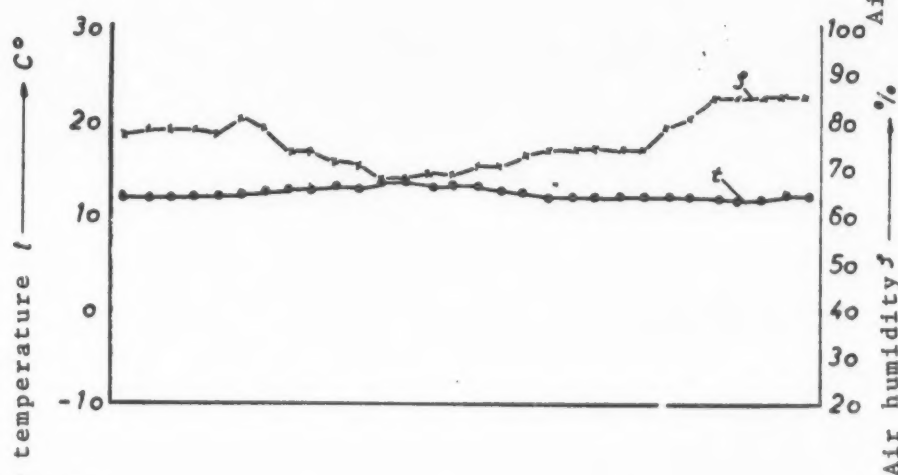
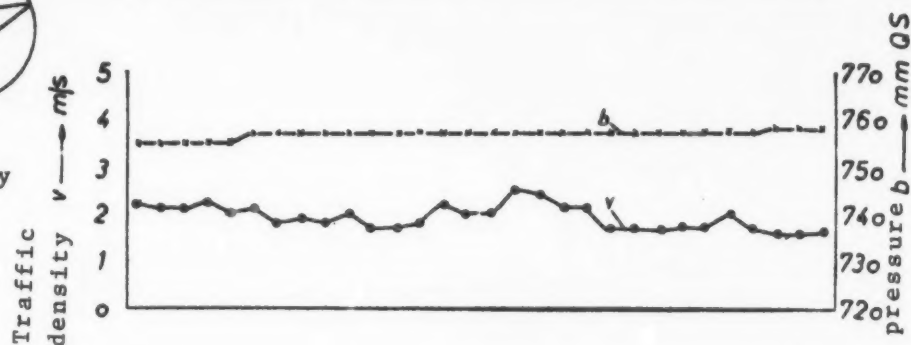
9

Date: Dec. 21, 1971



Wind frequency

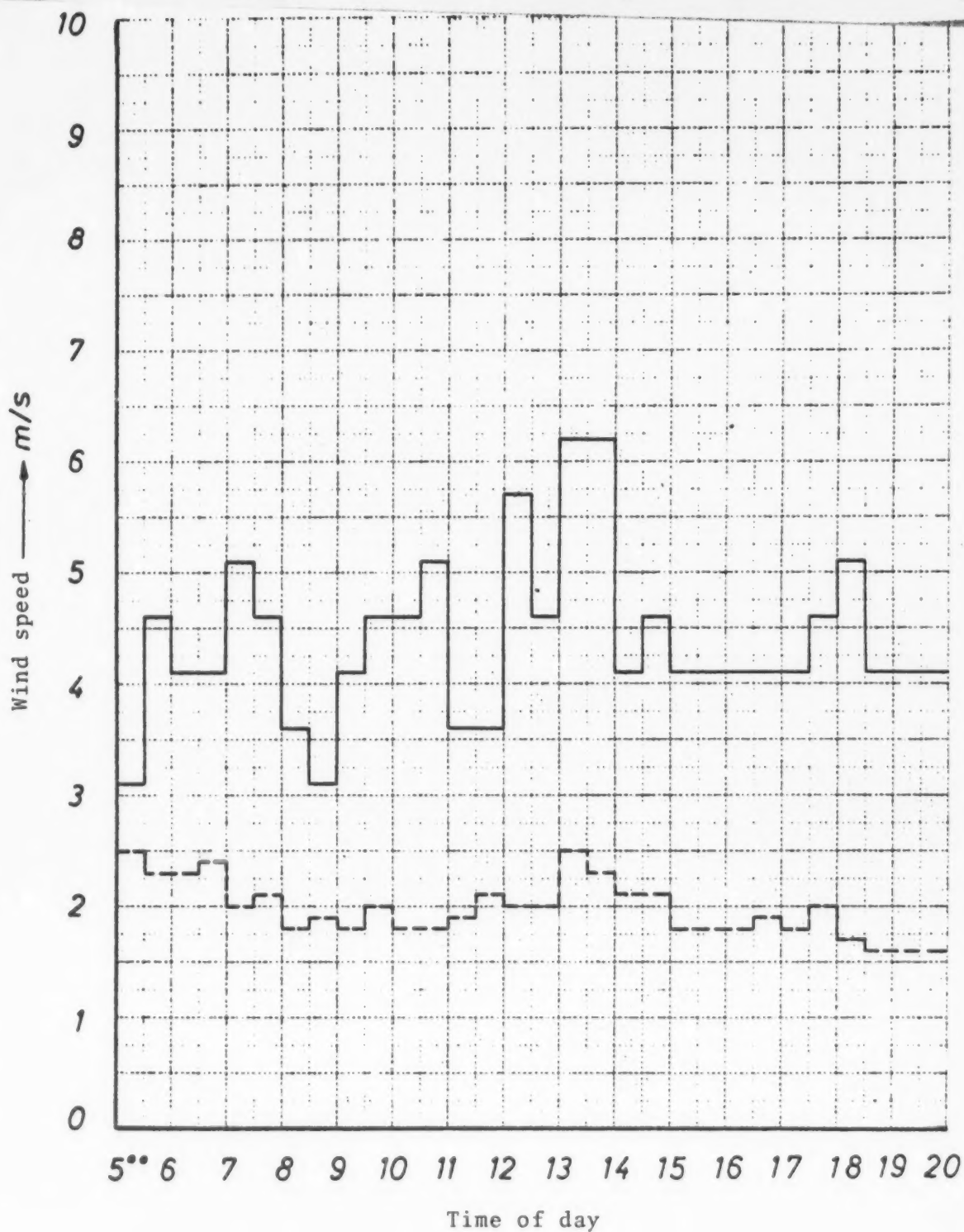
Wind direction related to street axis



TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions, city of Cologne  
 Measuring site: 9  
 Date: Dec. 21, 1971

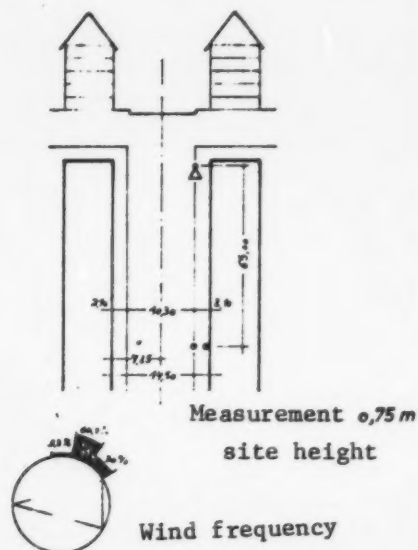
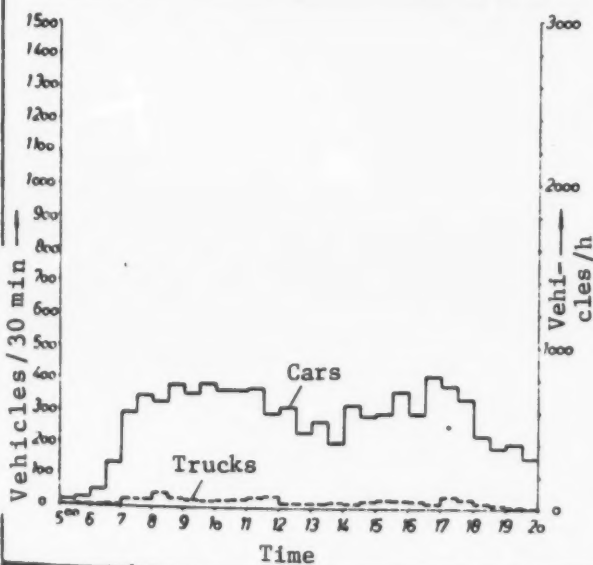


TÜV  
Rheinland

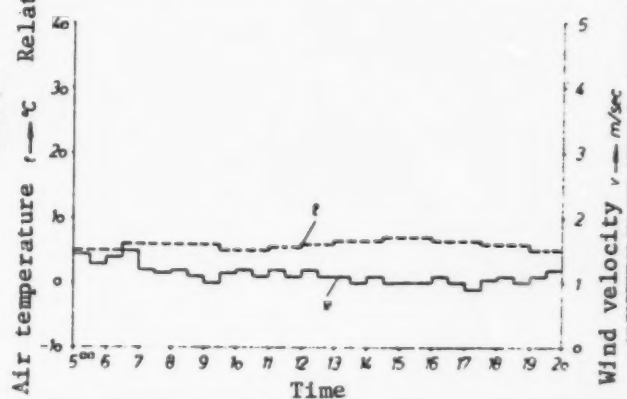
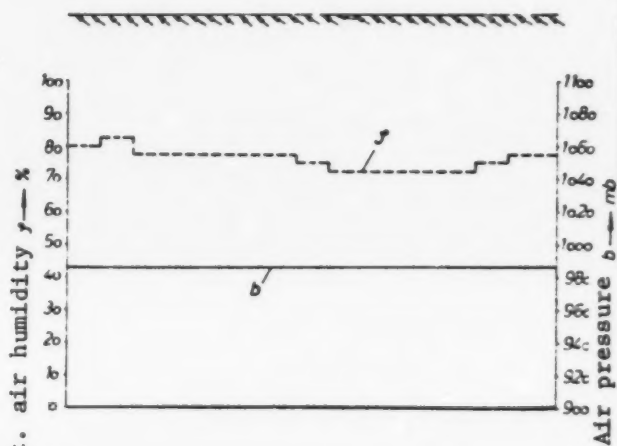
Daily lines for the course of the global  
and local wind speed

Immissions,  
city of Cologne  
Measuring site: 9  
Date: Dec. 21, 1971





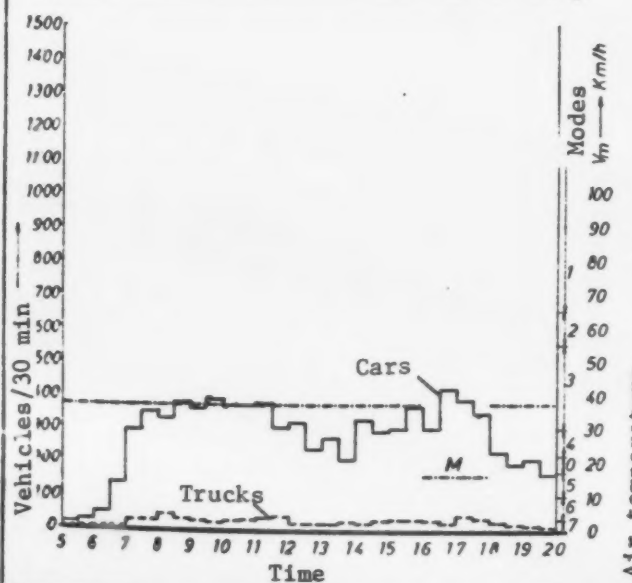
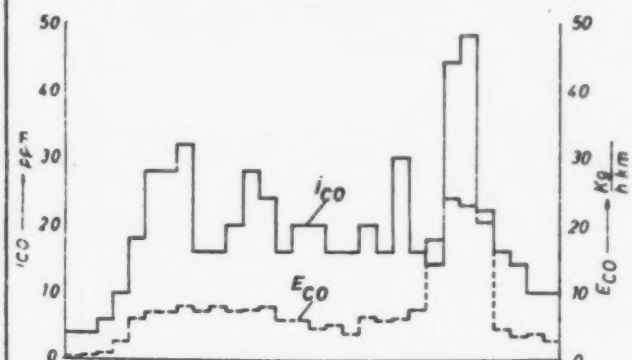
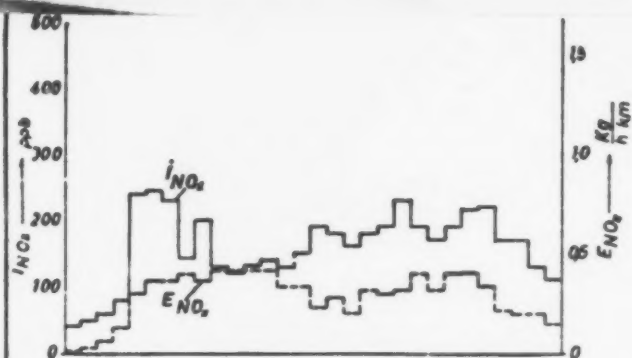
Wind direction relative to street axis



TUV  
Rheinland

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

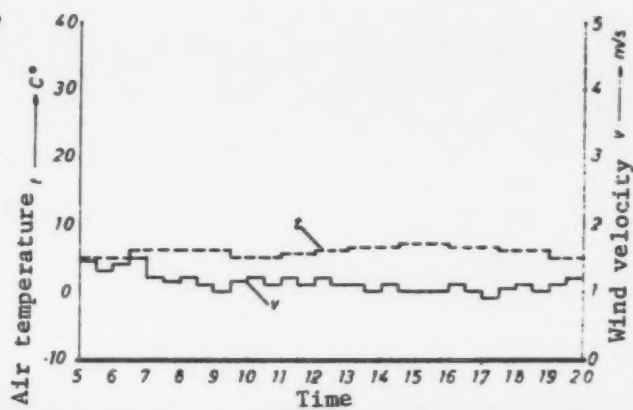
Emissions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 1, 1971



Wind direction relative to street axis



Wind frequency



TÜV  
Rheinland

Daily lines for traffic density, exhaust  
gas components (immission, emission) and  
meteorological quantities

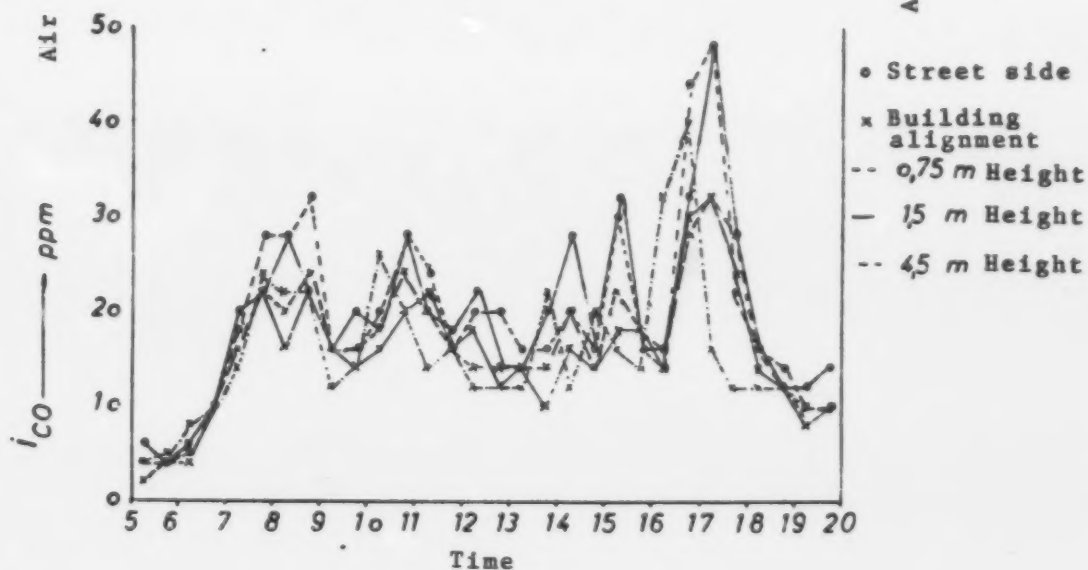
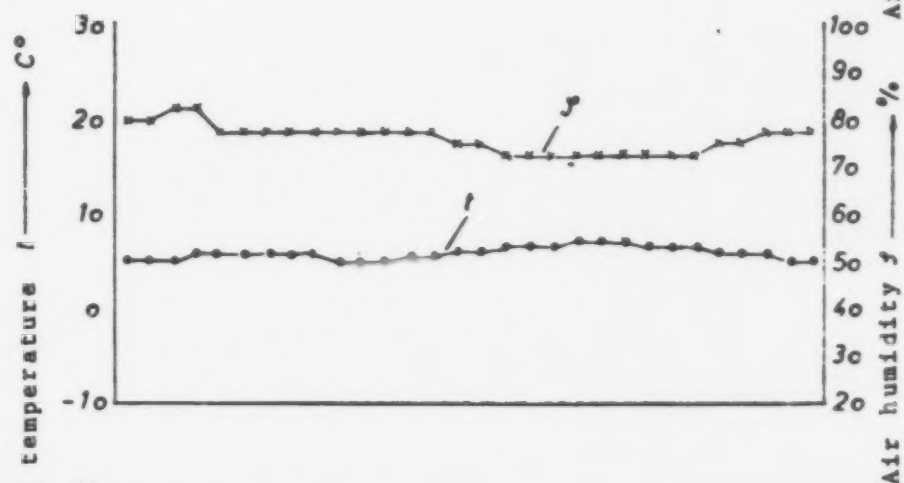
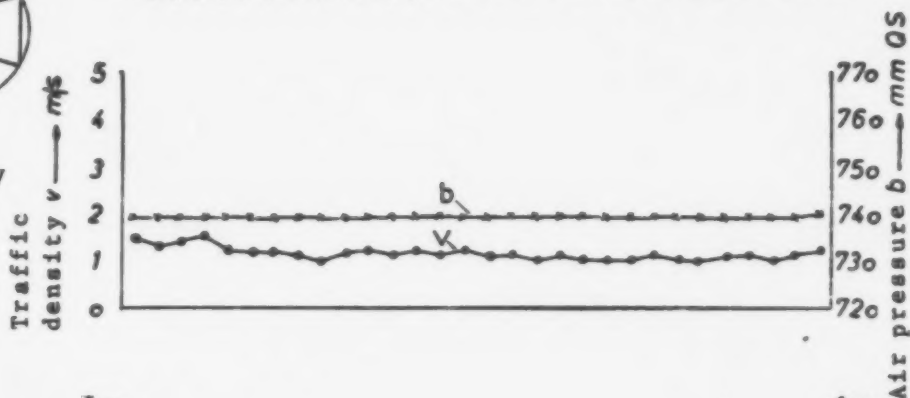
173

Immissions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 1, 1971



Wind direction related to street axis

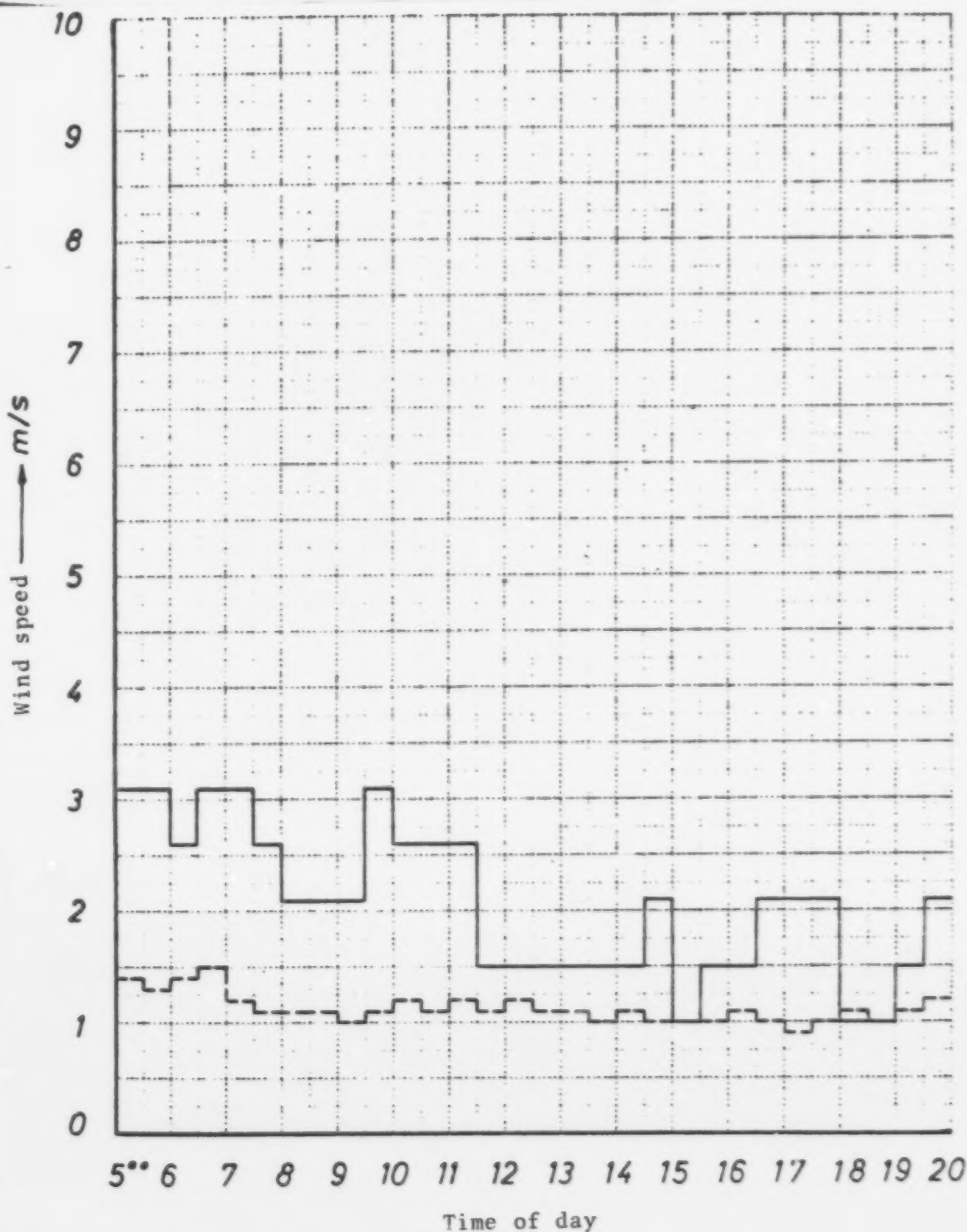
Wind frequency



TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

emissions,  
city of Cologne  
measuring site: 10  
date: Dec. 1, 1971

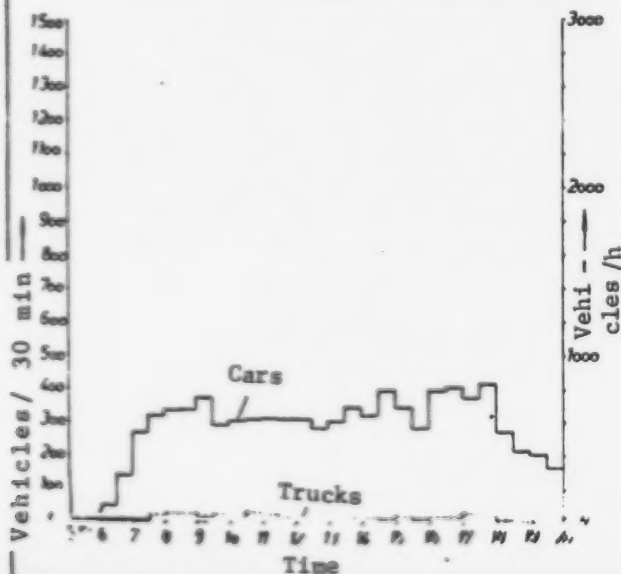
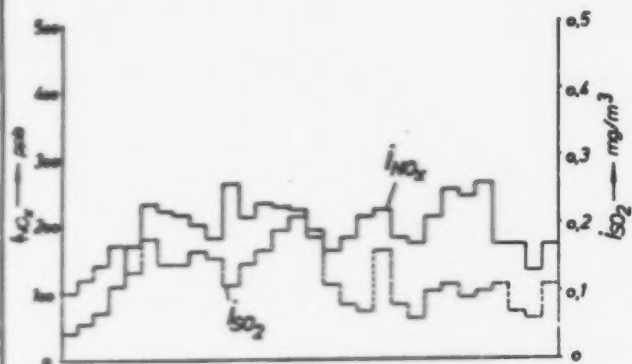


TÜV  
Rheinland

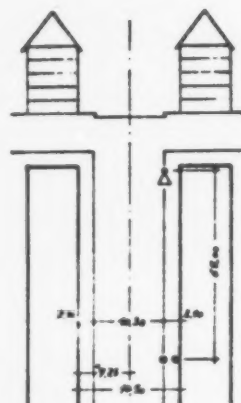
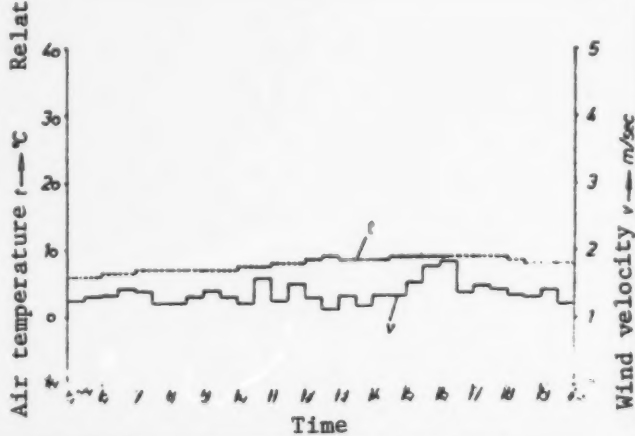
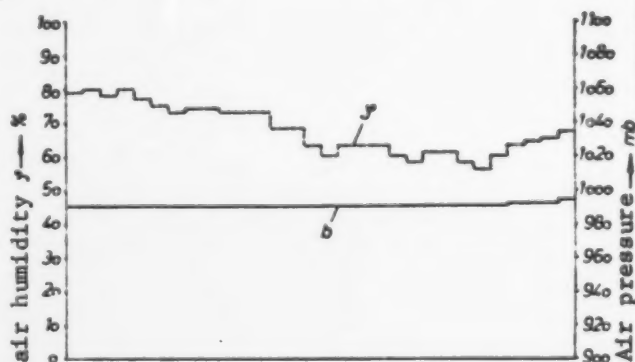
Daily lines for the course of the global  
and local wind speed.

Anna. von  
Cologne  
Measuring site: 10  
Date: Dec. 1, 1971





Wind direction relative to street axis



Measurement 0,75 m  
site height

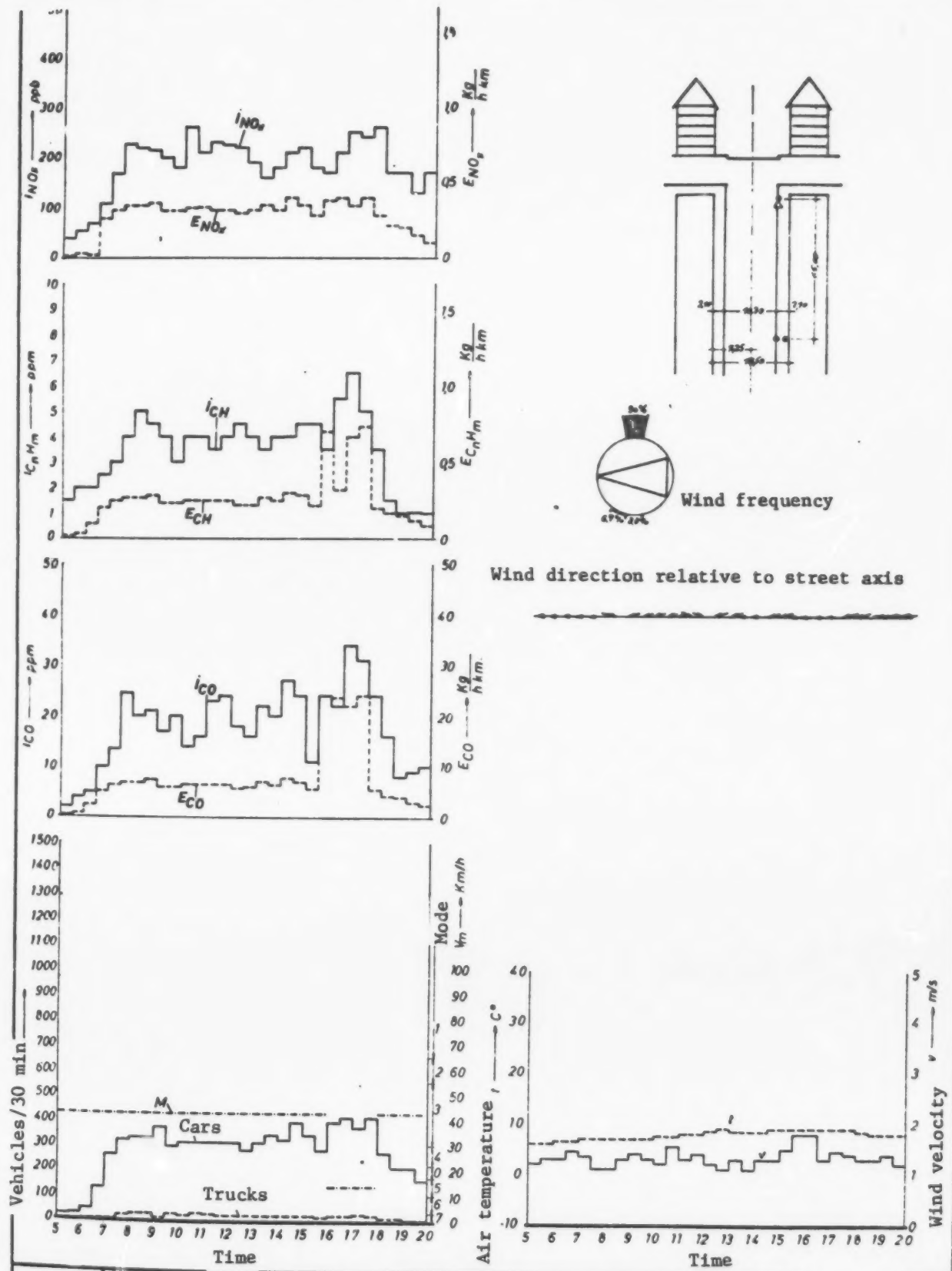


Wind frequency

TÜV  
Rheinland

Daily lines for the course of traffic  
density, exhaust gas components and  
meteorological variables

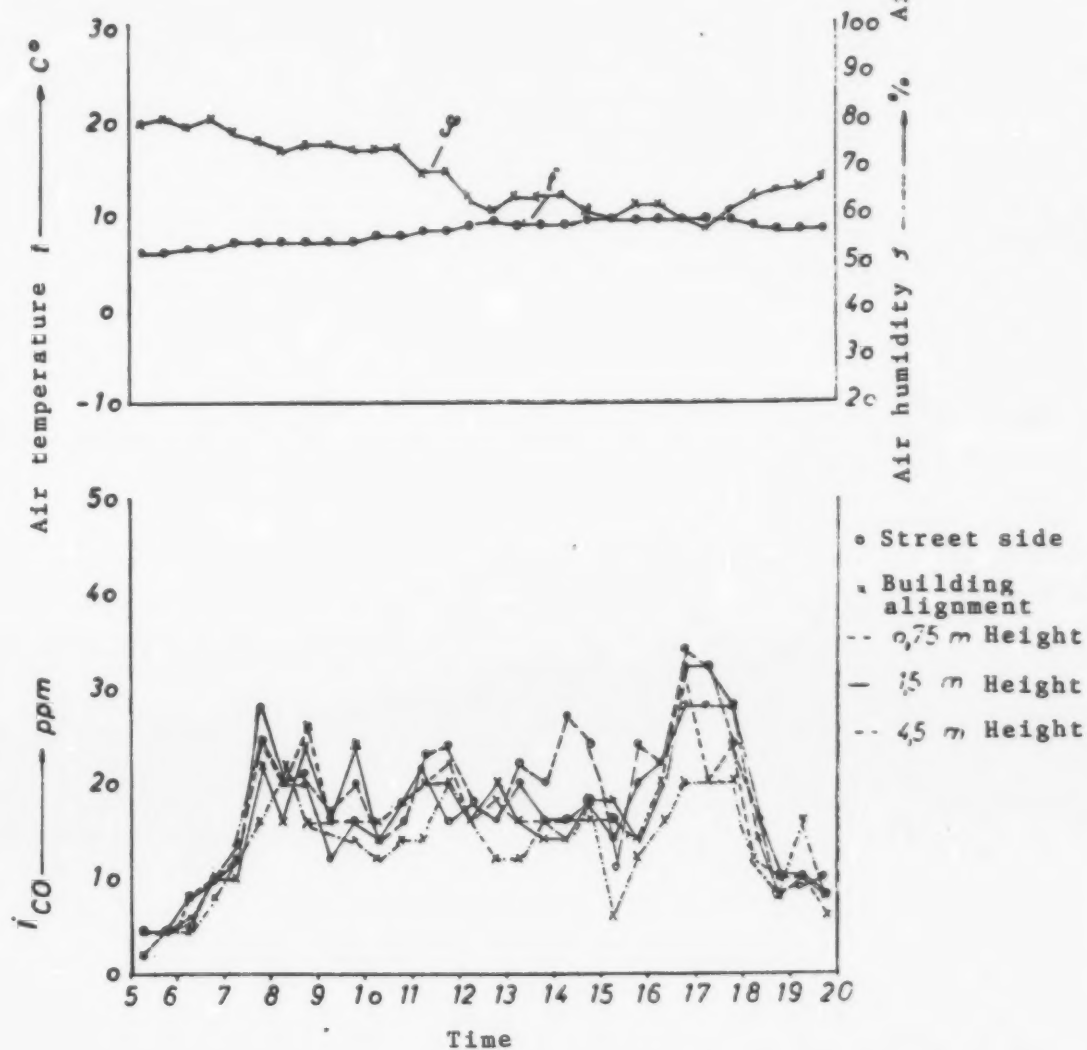
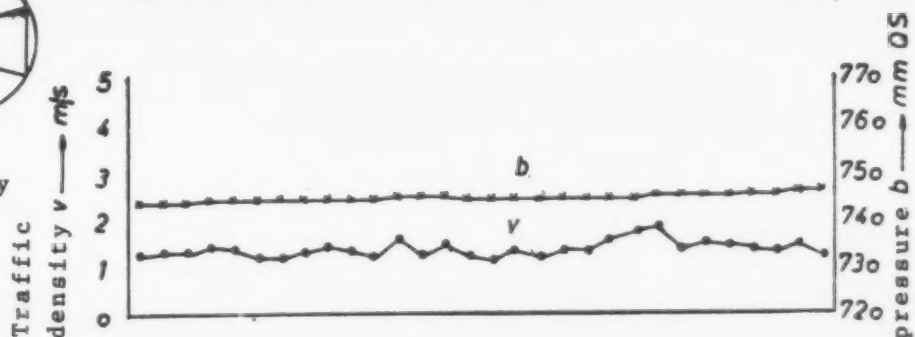
Immissions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 2, 1971



TÜV  
Rheinland

Daily lines for traffic density, exhaust gas components (immission, emission) and meteorological quantities

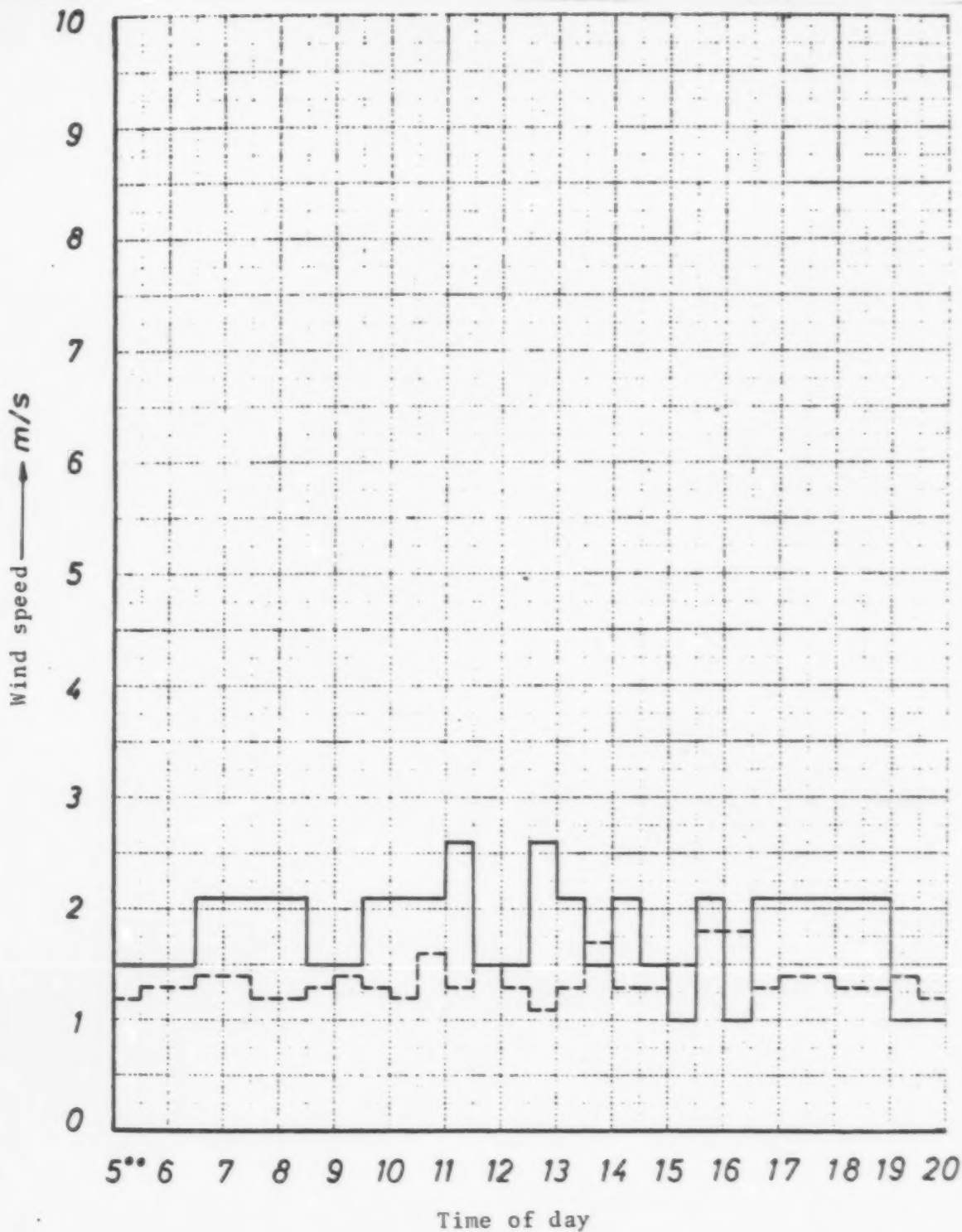
Immissions, city of Cologne  
Measuring site: 10  
Date: Dec. 2, 1971



TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 2, 1971

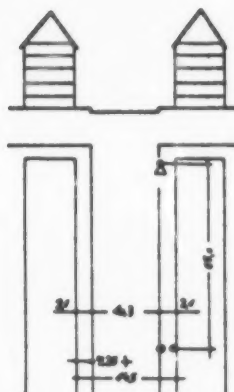
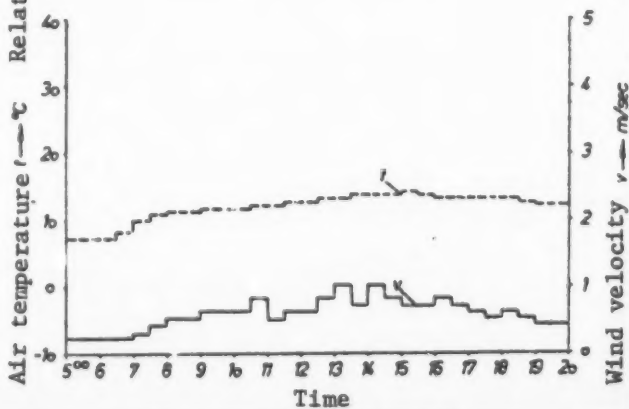
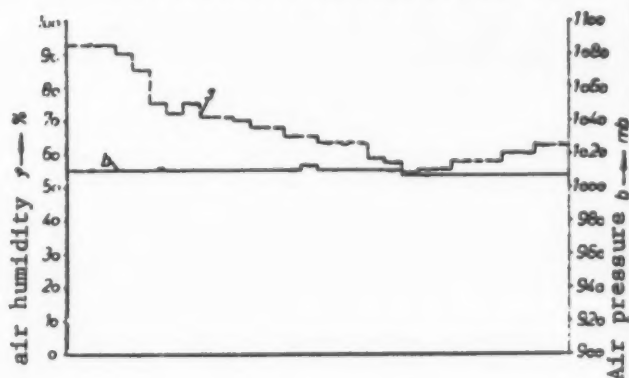
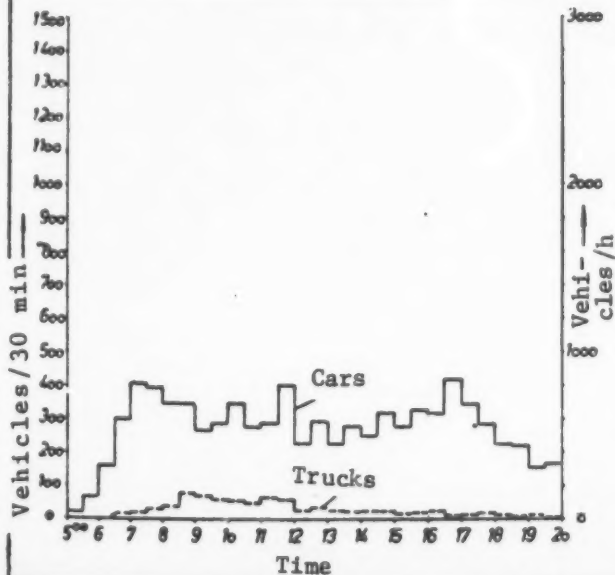
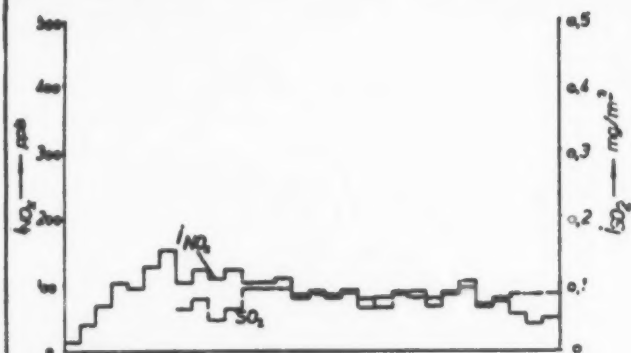


TÜV  
Rheinland

Daily lines for the course of the global and local wind speed.

in ssions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 2, 1971





Wind frequency

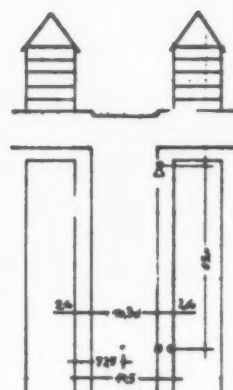
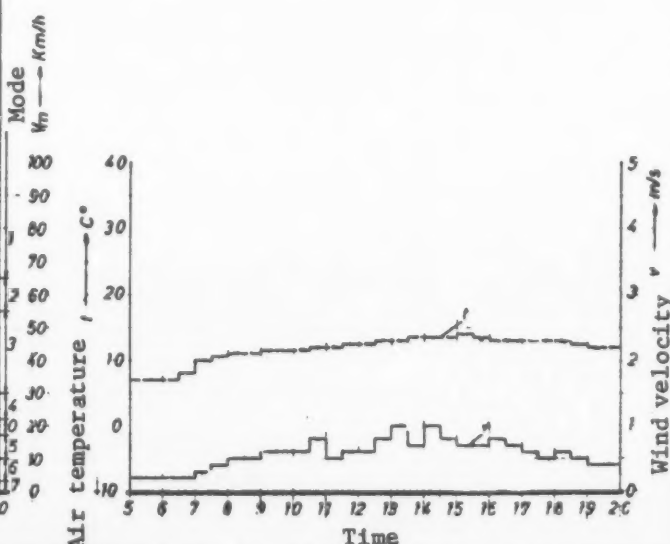
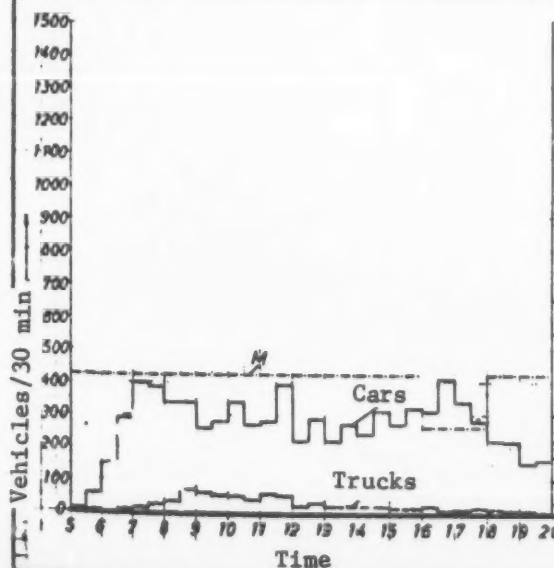
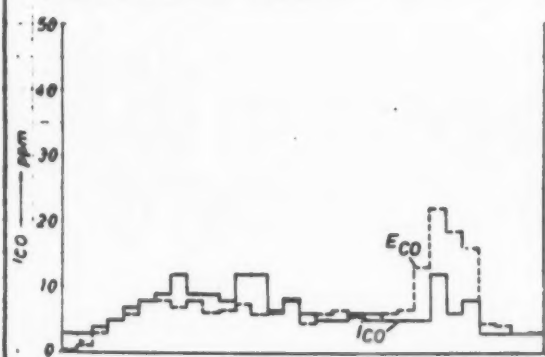
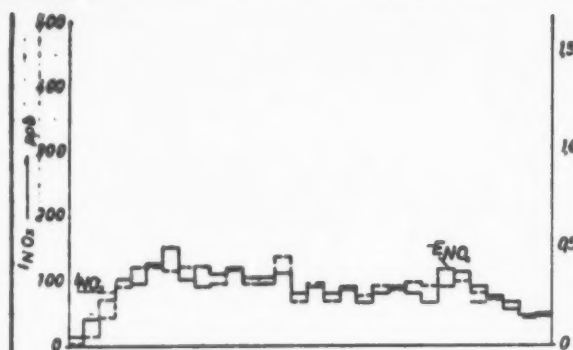
Wind direction relative to street axis



TÜV  
Frankfurt

Daily lines for the course of traffic density, exhaust gas components and meteorological variables

Immissions,  
city of Cologne  
Measuring site: 10  
Date: April 21, 1971



Wind frequency

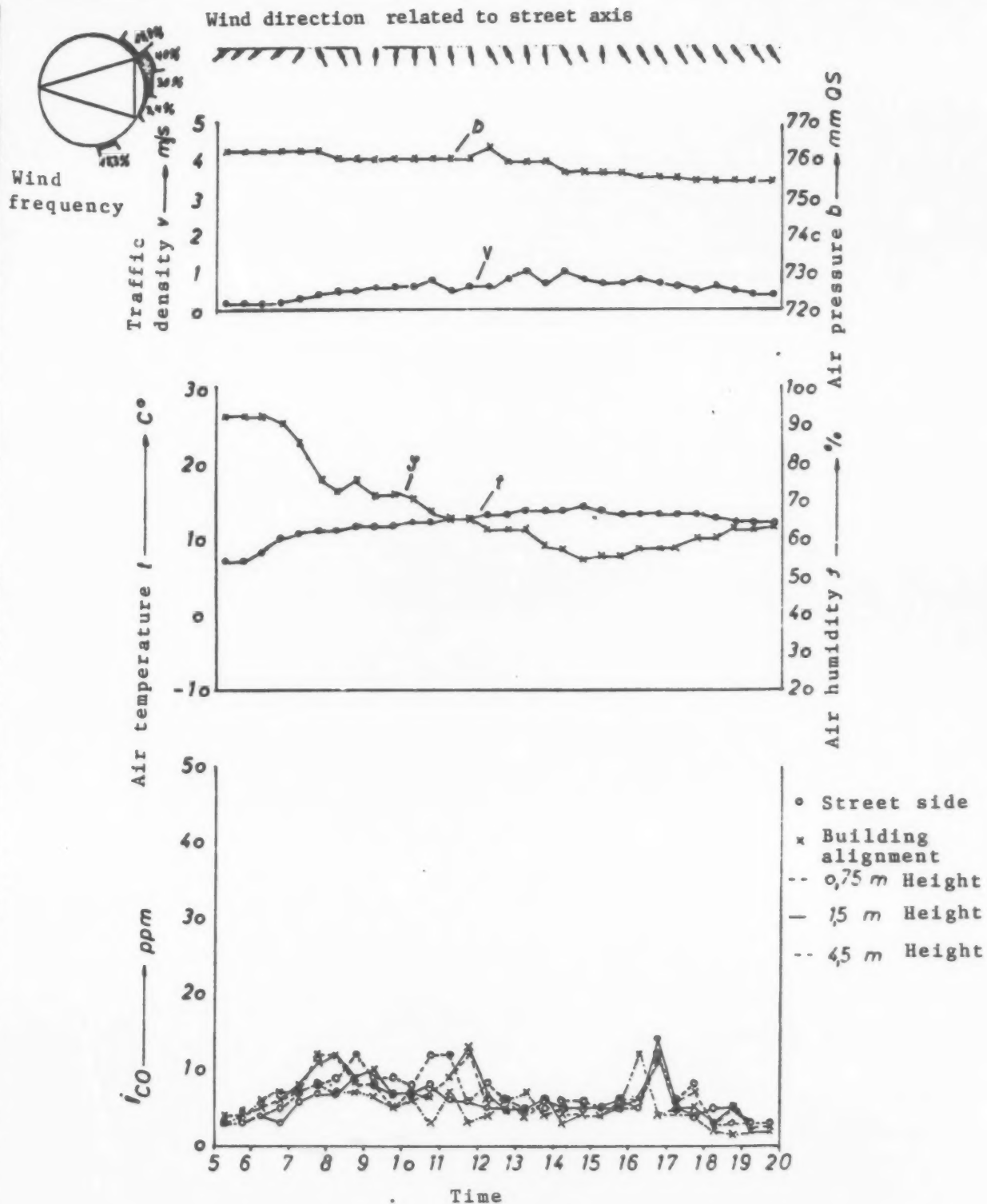
Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for traffic density, exhaust  
gas components (immission, emission) and  
meteorological quantities

Immissions,  
city of Cologne  
Measuring site: 10  
Date: April 21, 1972

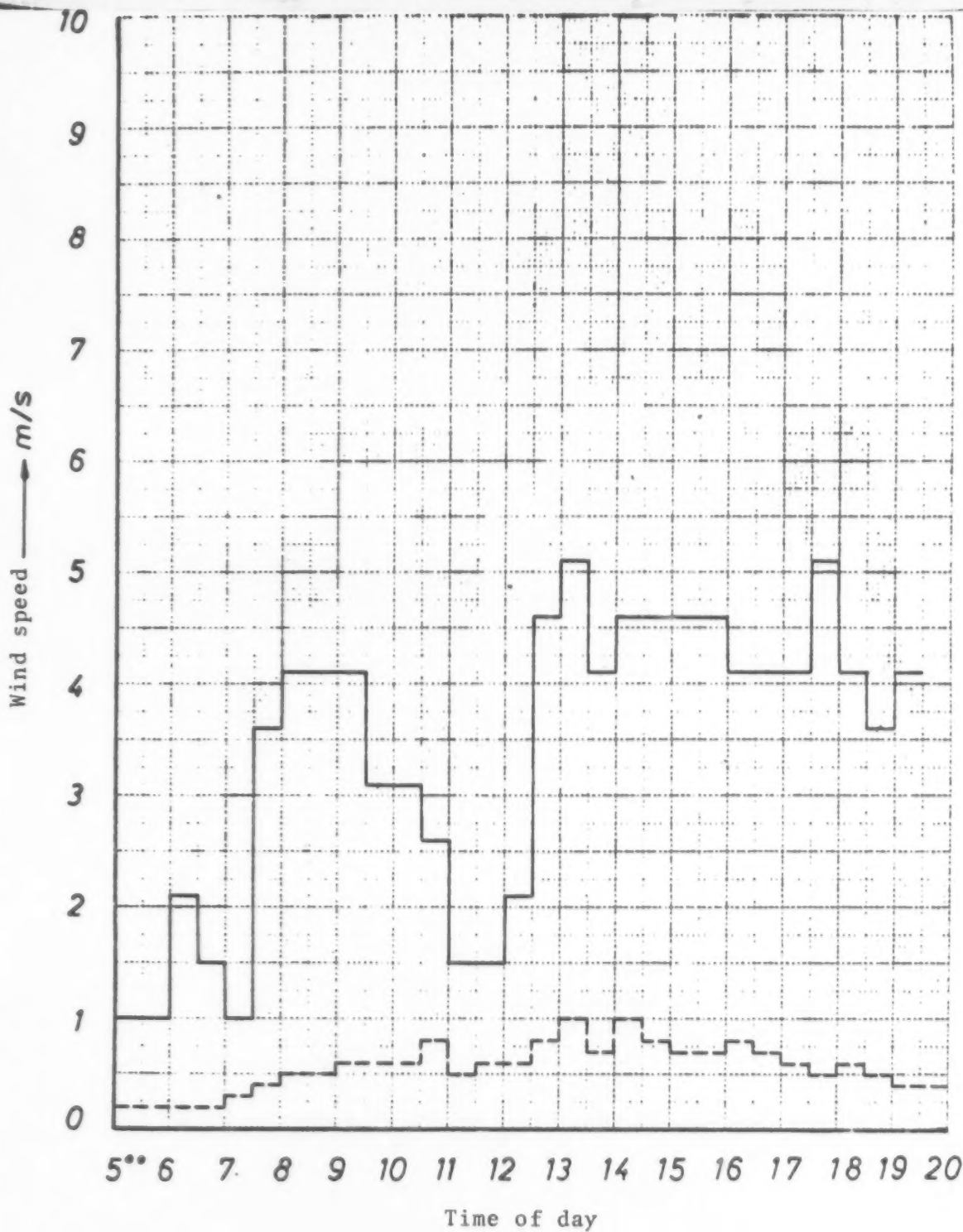


TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissionen

Immissions,  
city of Cologne  
Measuring site: 10  
Date: April 21, 1972

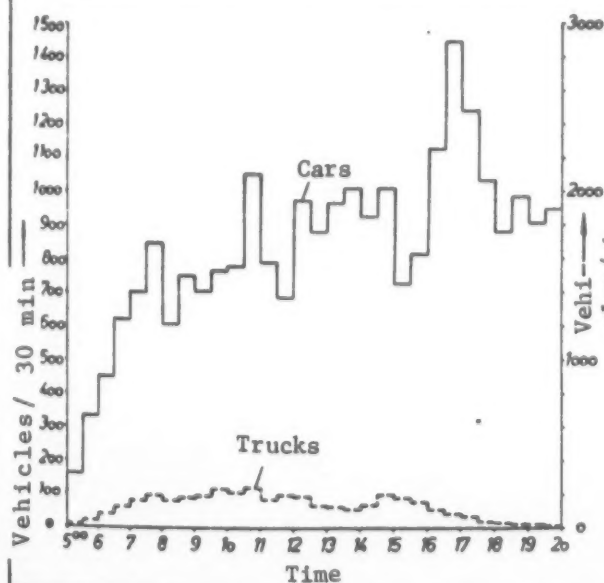
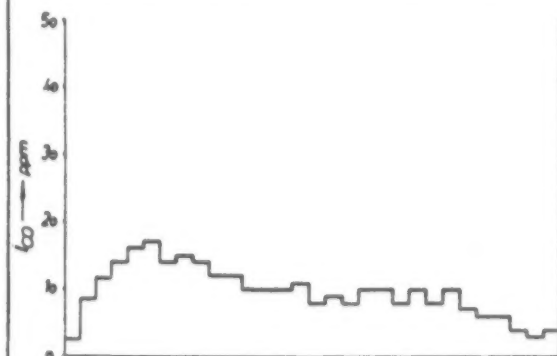
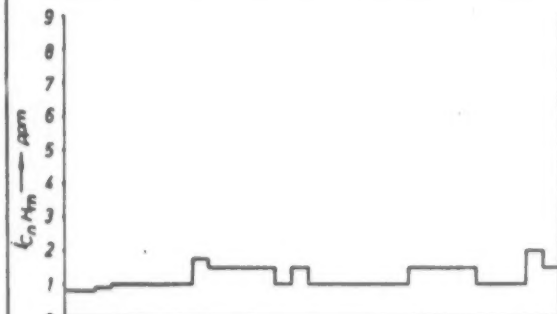
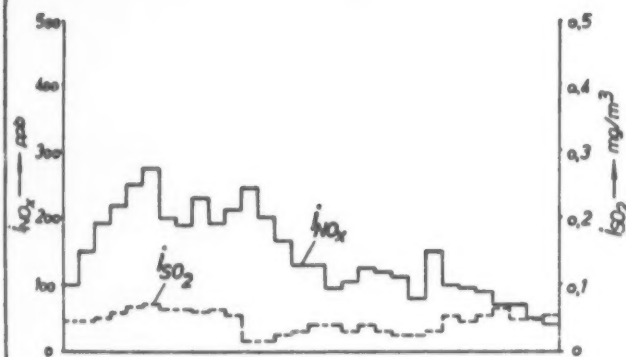


— Global wind speed  
 ---- Local wind speed

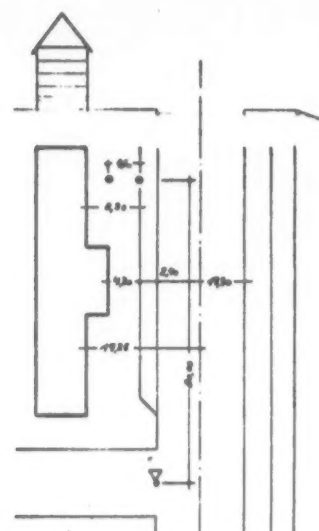
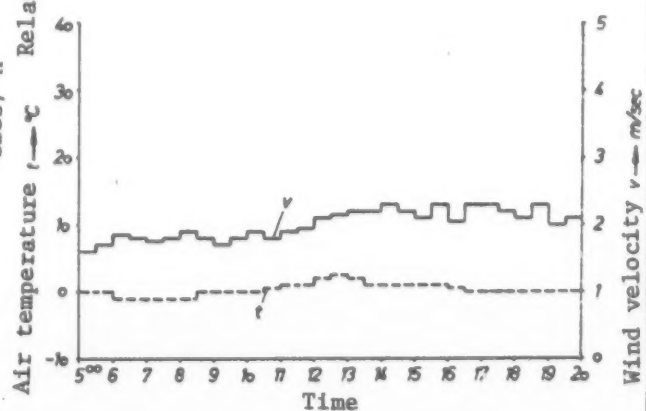
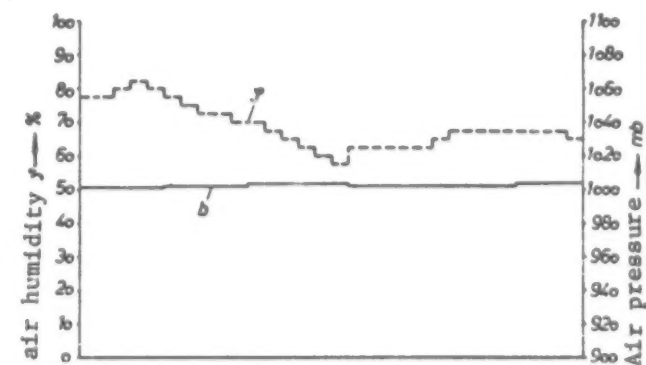
TÜV  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 10  
 Date: April 21, 1972



Wind direction relative to street axis



Measurement 0.75 m  
site height



Wind frequency

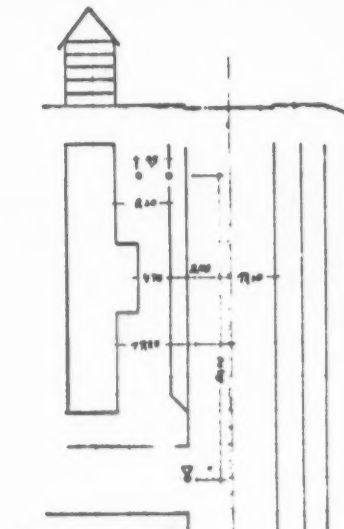
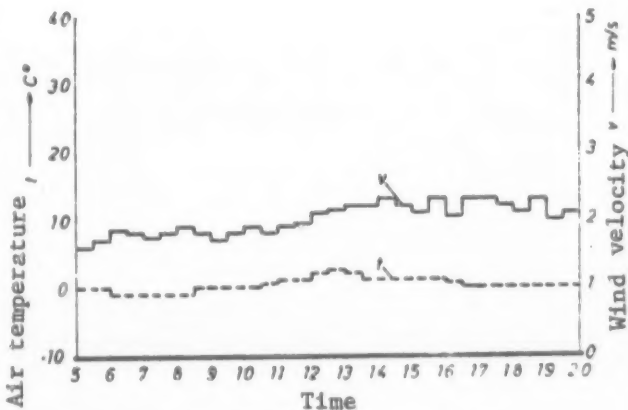
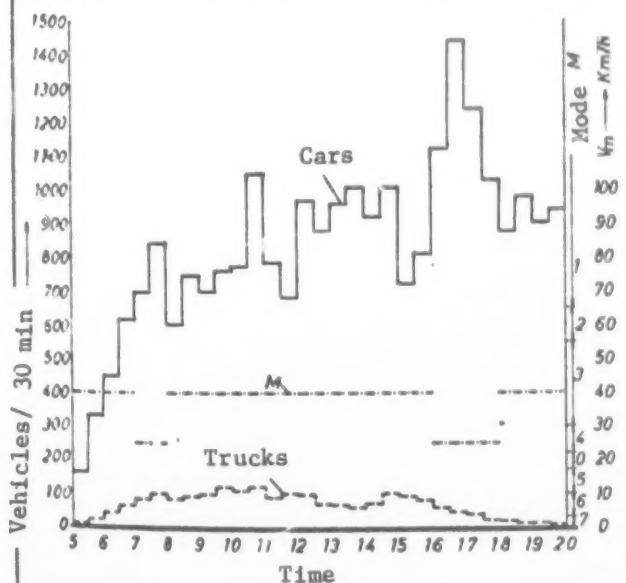
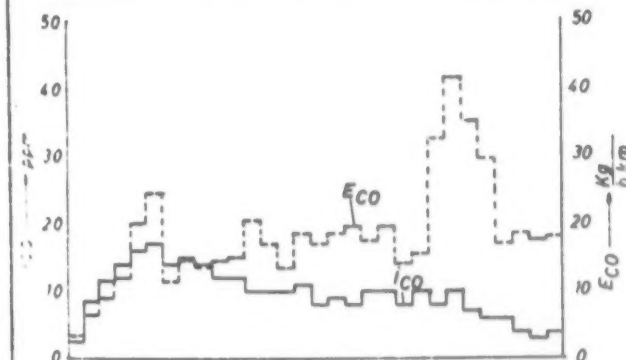
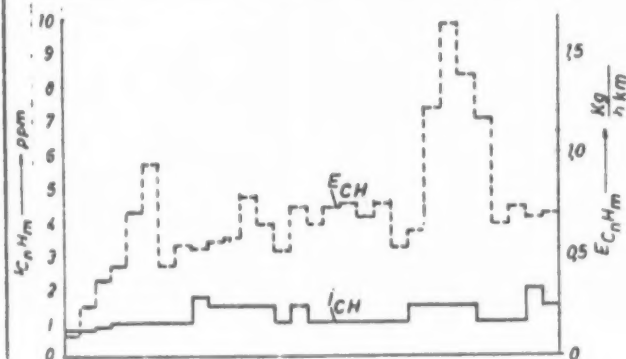
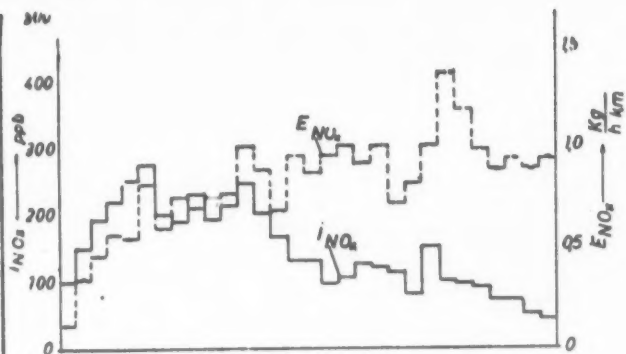
TÜV  
Rheinland

Daily lines for the course of traffic  
density, exhaust gas components and  
meteorological variables

184

Immissions,  
city of Cologne  
Measuring site: 11  
Date: Dec. 29, 1971





Wind frequency

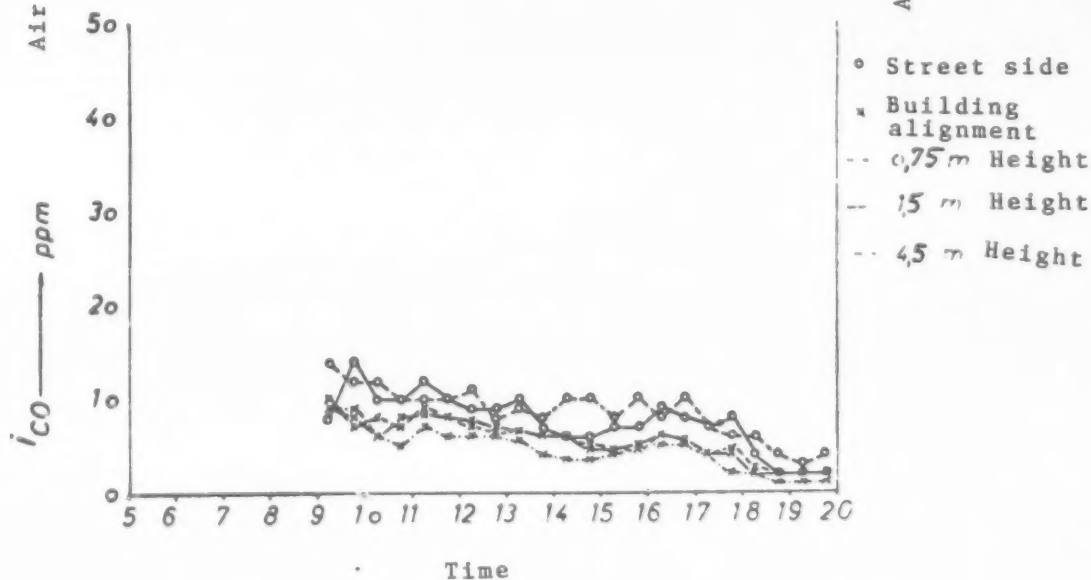
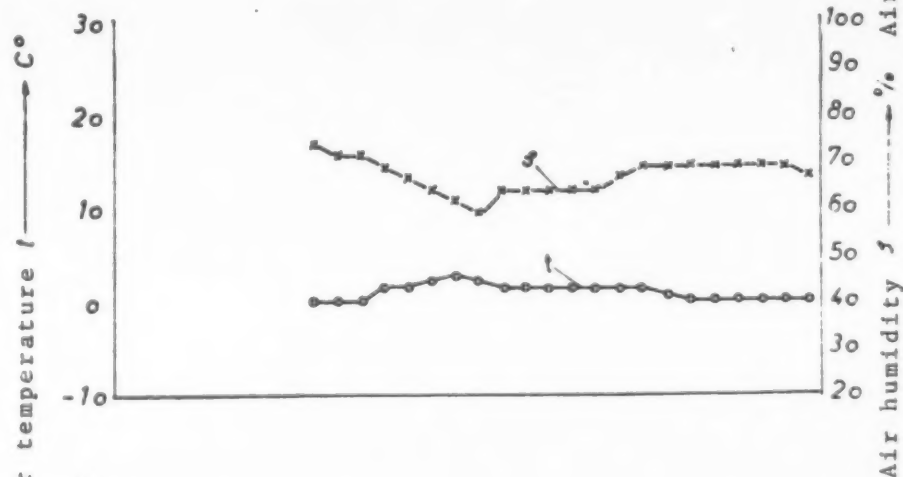
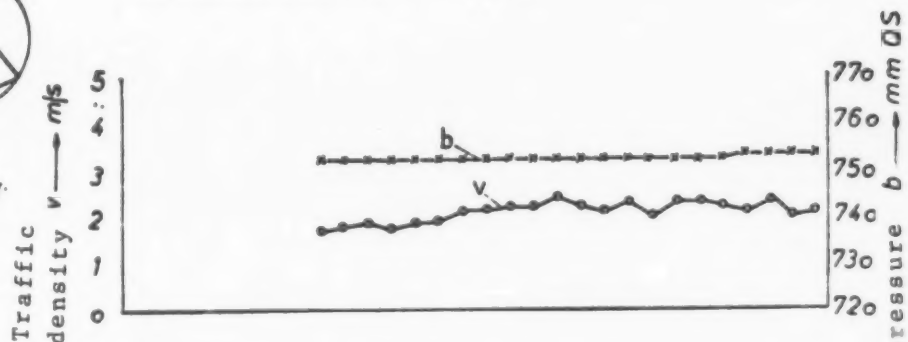
Wind direction relative to street axis



Wind direction related to street axis



Wind frequency

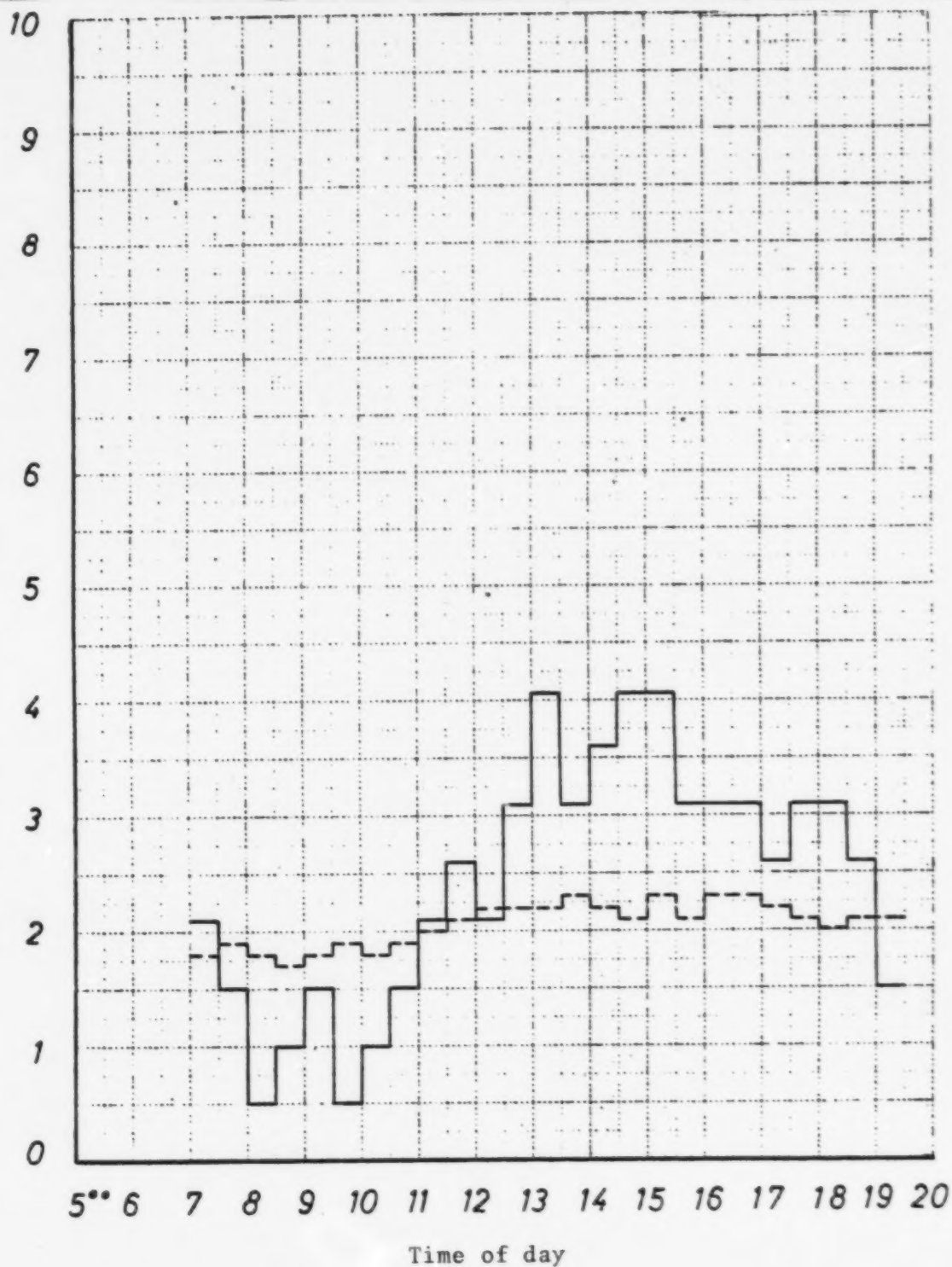


TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne  
Measuring site: 11  
Date: Dec. 29, 1971

Wind speed —→ m/s

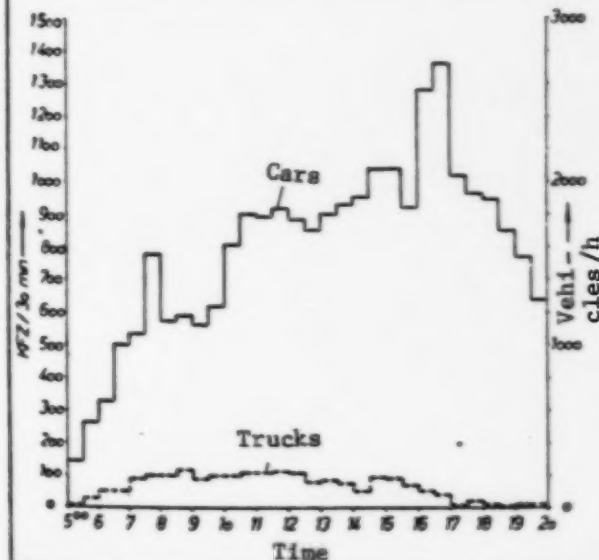
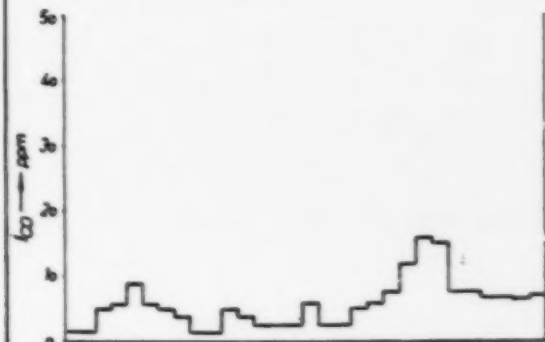
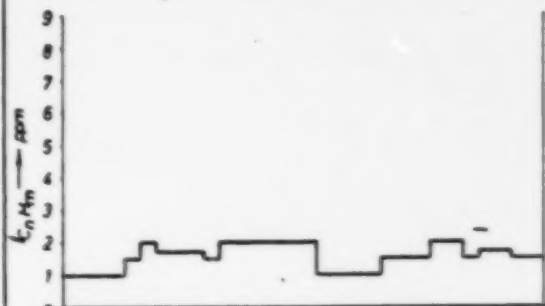
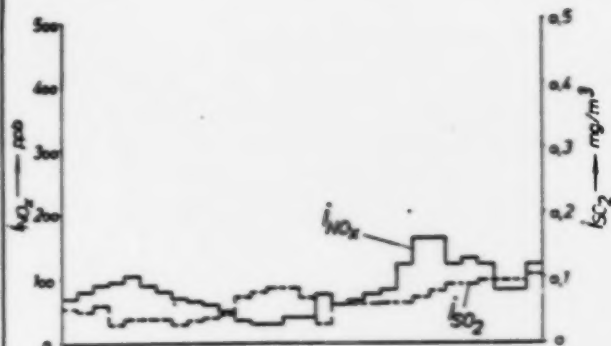


— Global wind speed  
---- Local wind speed

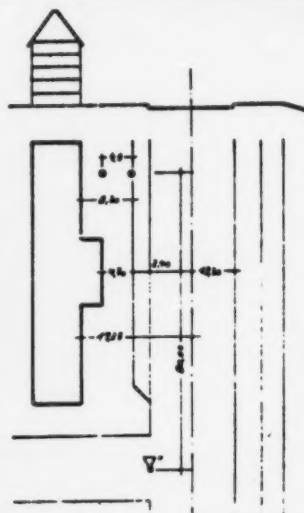
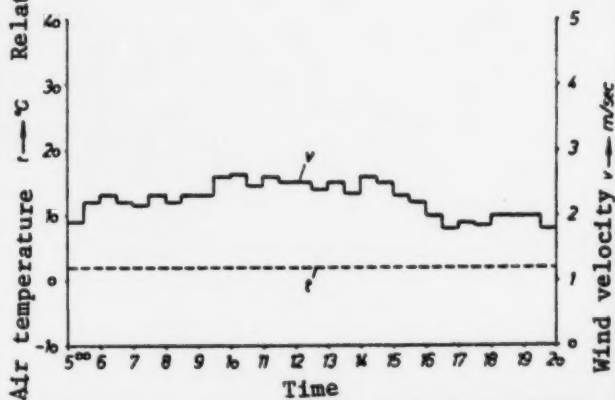
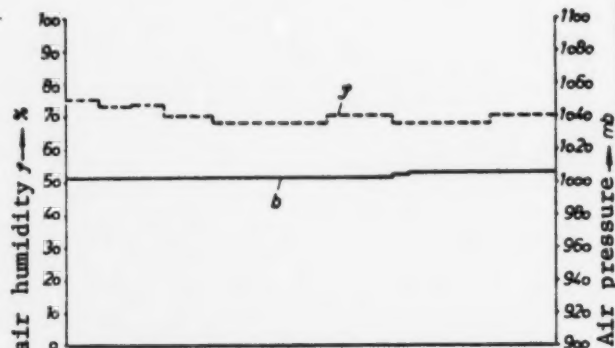
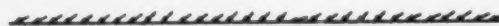
TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed

Immissions,  
city of Cologne  
Measuring site: 11  
Date: Dec. 29, 1971



Wind direction relative to street axis



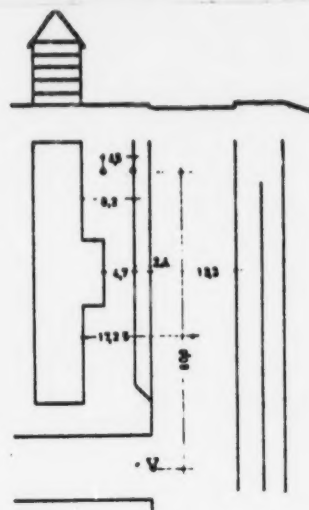
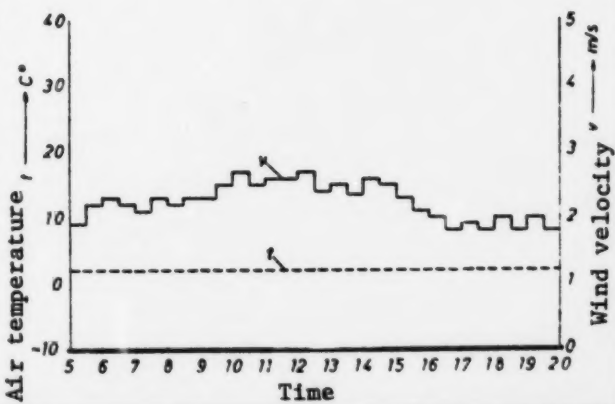
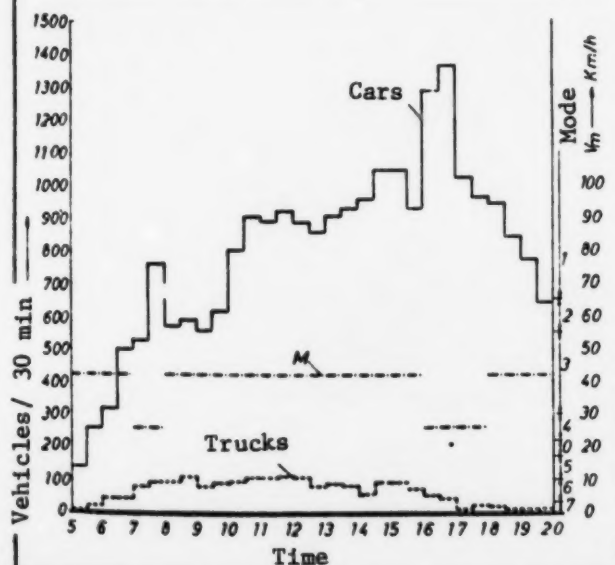
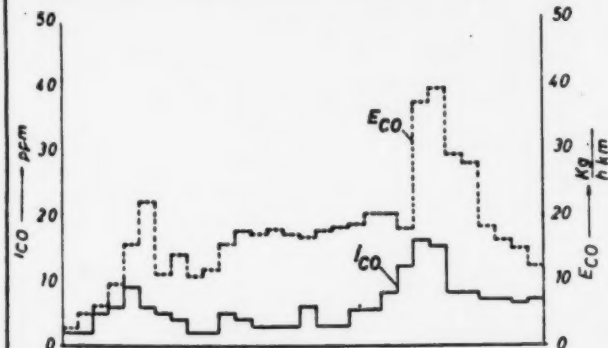
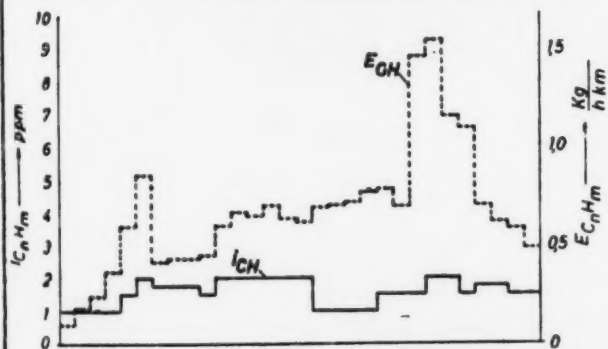
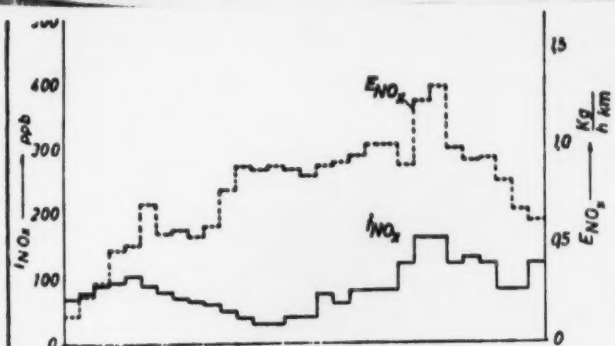
Measurement 0,75 m  
site height

Wind frequency

TÜV  
Rheinland

Daily lines for the course of traffic  
density, exhaust gas components and  
meteorological variables

Immissions,  
city of Cologne  
Measuring site: 10  
Date: Dec. 30, 1971



Wind frequency

Wind direction relative to street axis



TÜV  
Rheinland

Daily lines for traffic density, exhaust  
gas components (immission, emission) and  
meteorological quantities

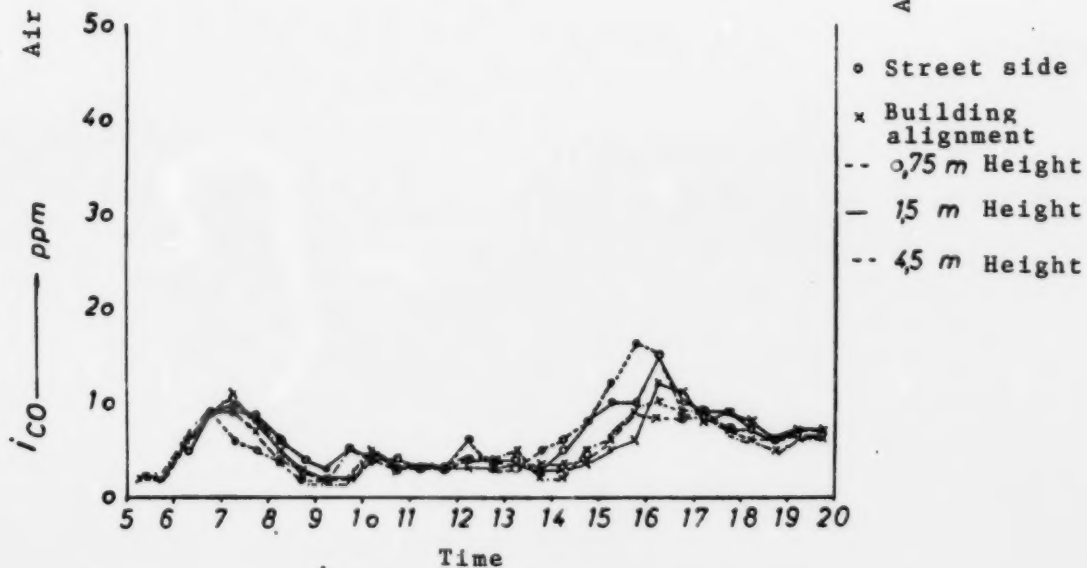
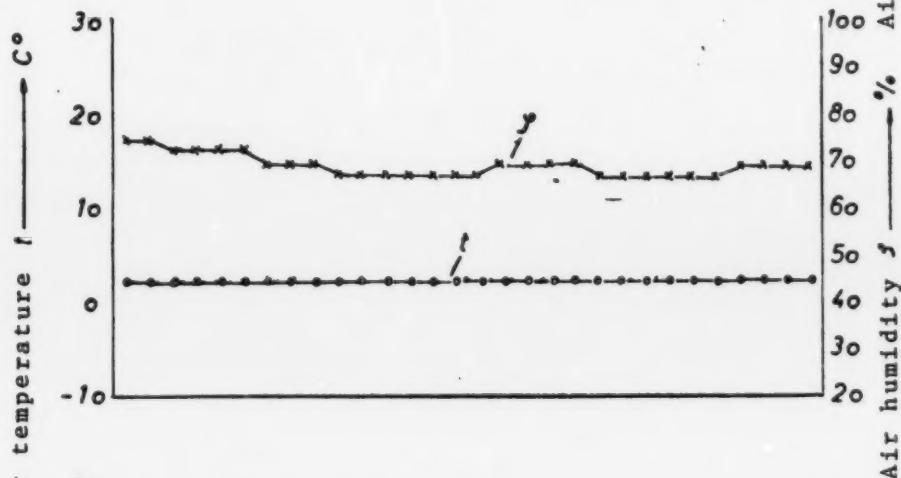
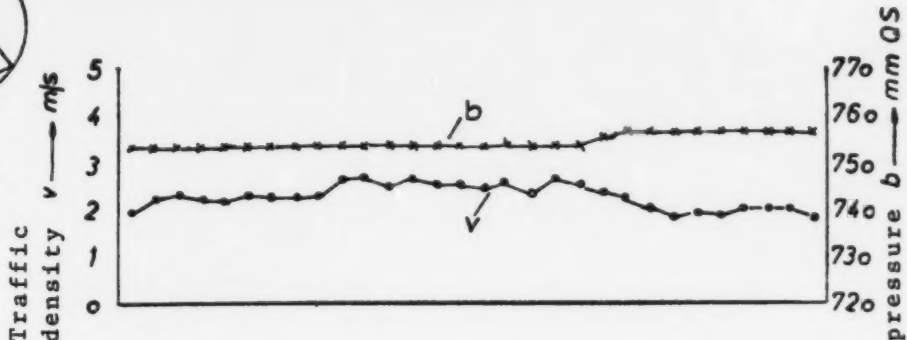
Immissions,  
city of Cologne  
Measuring site: 11  
Date: Dec. 30, 1971





Wind direction related to street axis

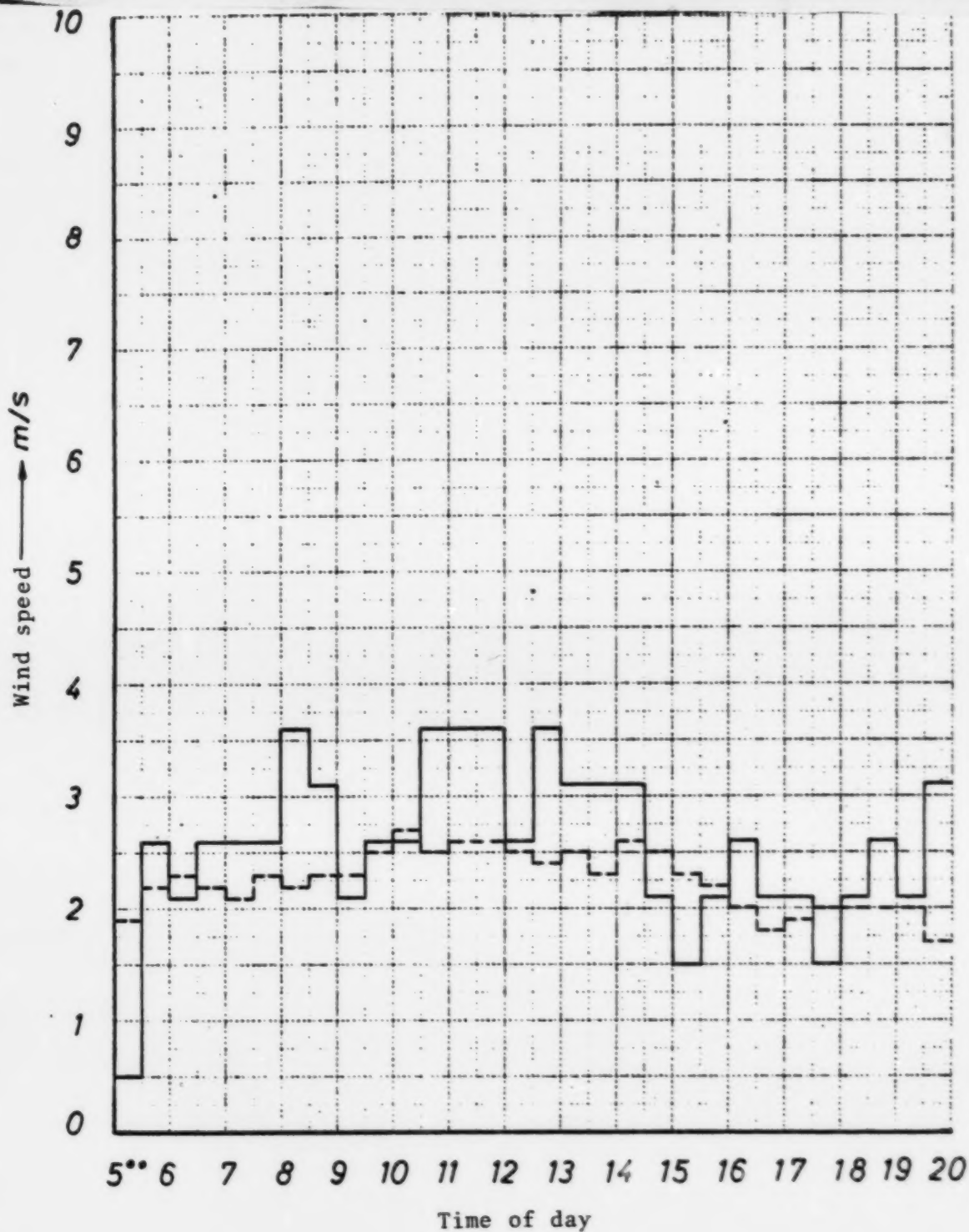
Wind frequency



TÜV  
Rheinland

Daily lines of CO concentration at various altitudes and meteorological variables.

Immissions,  
city of Cologne.  
Measuring site: 11  
Date: Dec. 30, 1971



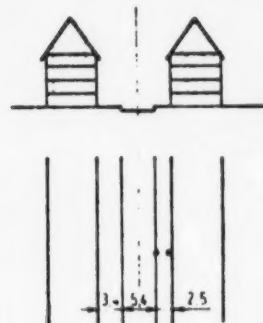
TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 11  
Date: Dec. 30, 1971

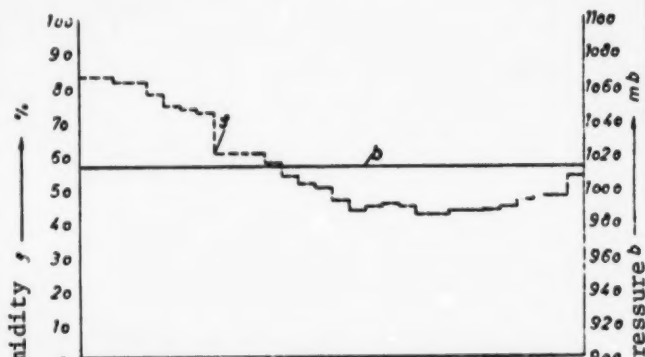
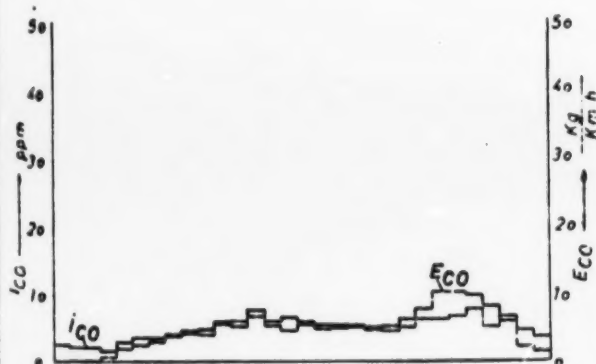


Building  
 • alignment  
 • Street side  
 --- 0.75 m Height  
 --- 1.5 m Height  
 --- 4.5 m Height

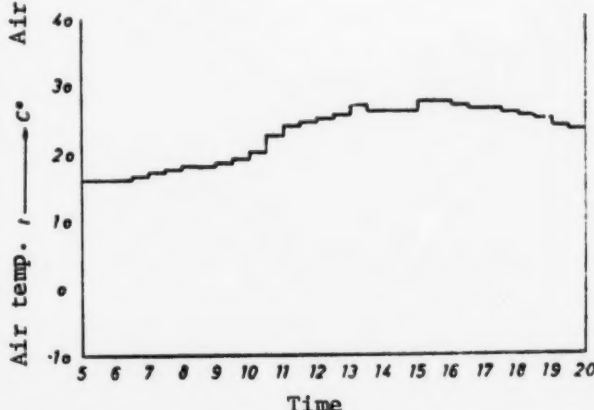
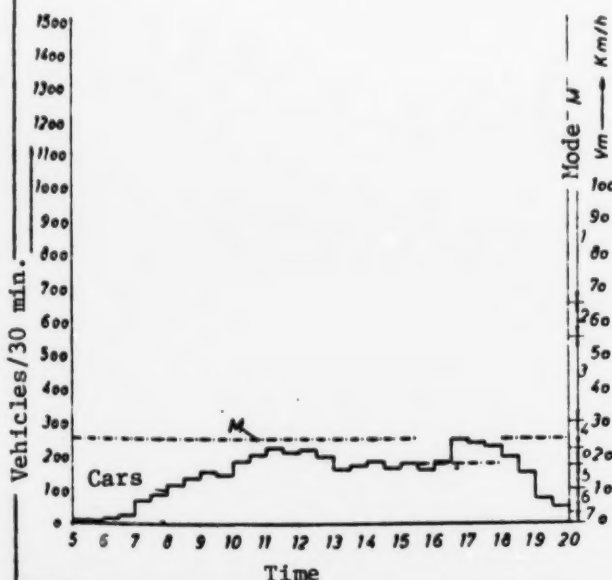


Wind frequency

Wind direction relative to street axis



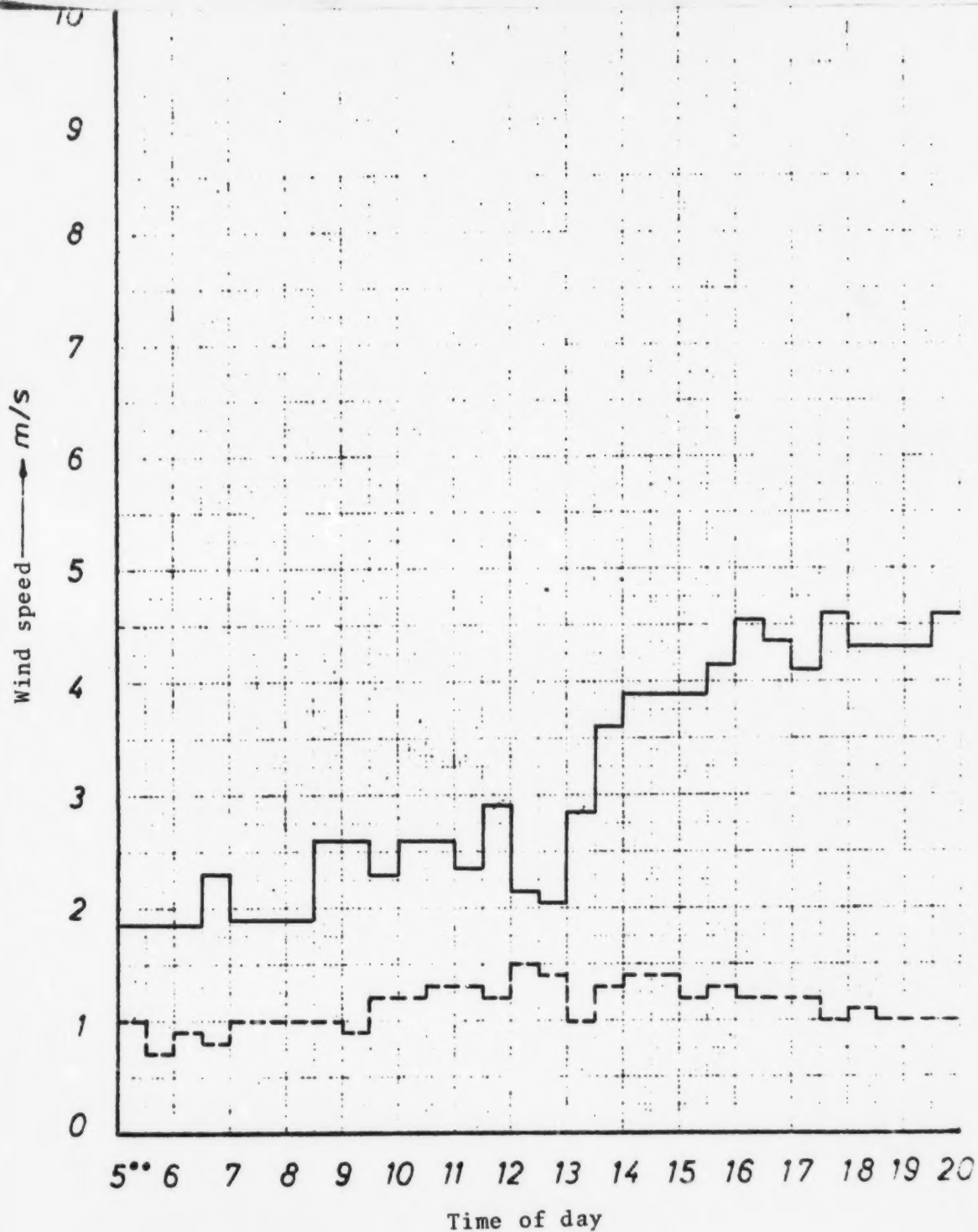
Air pressure



TÜV  
 Rheinland

Daily lines for the course of the exhaust  
 gas component CO (immission, emission), CO  
 concentration at various heights, traffic  
 density and meteorological quantities.

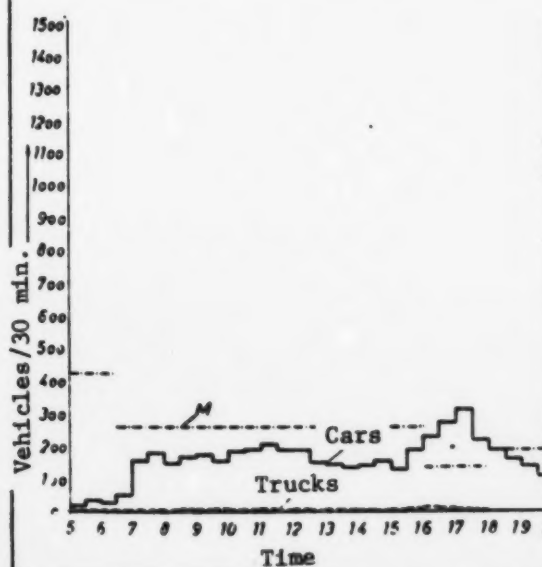
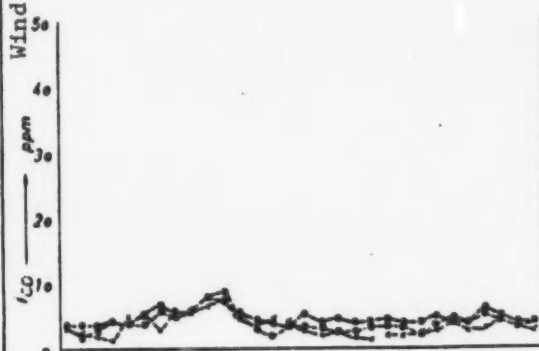
Immissions,  
 city of Cologne  
 Measuring site: 12  
 Date: July, 1971



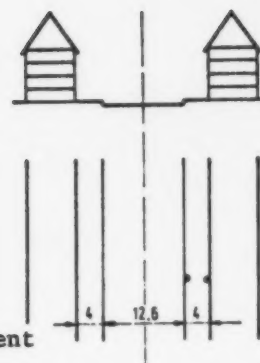
TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 12  
Date: July, 1971

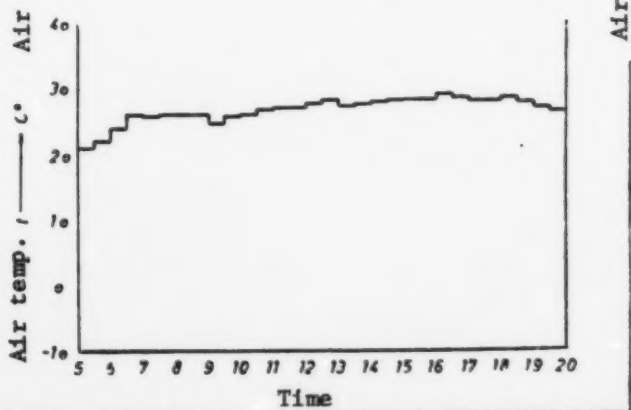
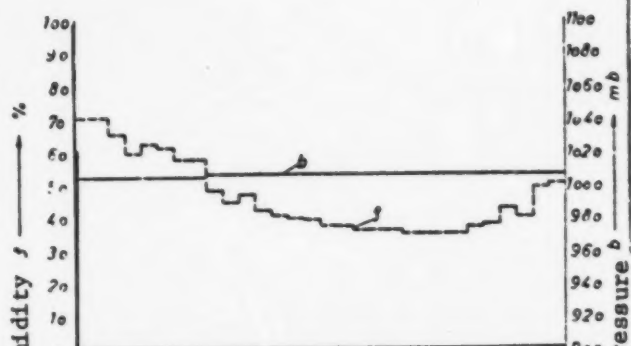
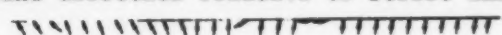


- Building alignment
- Street side
- 0.75 m Height
- 1.5 m Height
- 4.5 m Height



Wind frequency

Wind direction relative to street axis

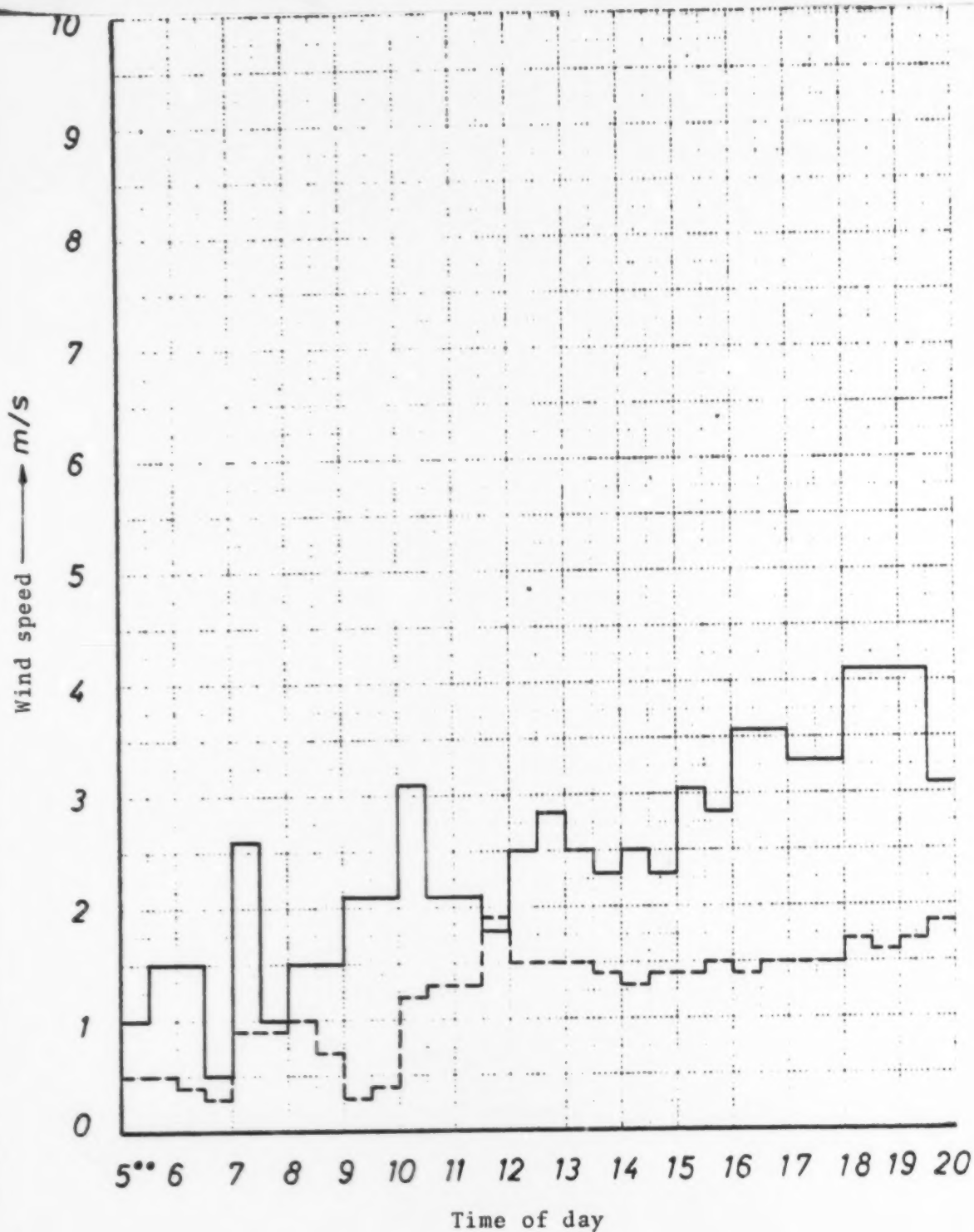


TÜV  
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Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 13  
Date: July, 1971



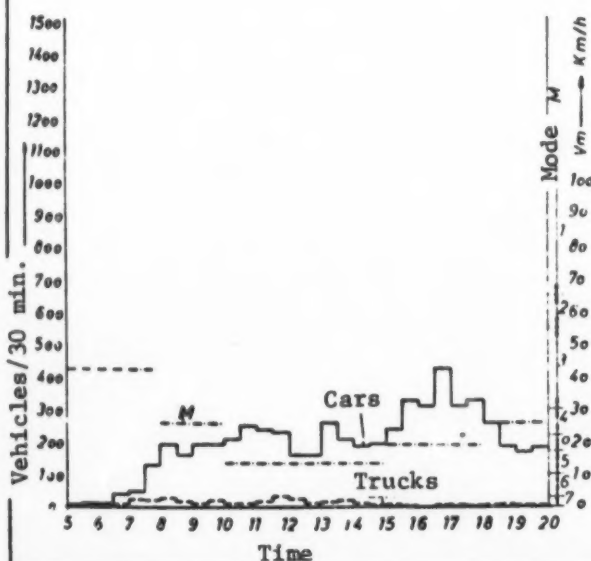
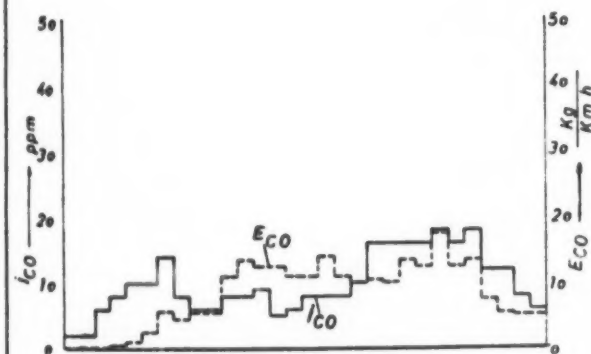
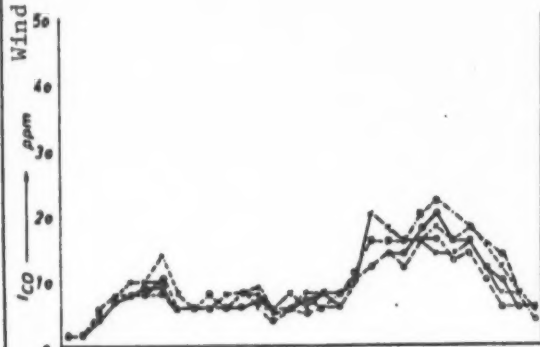
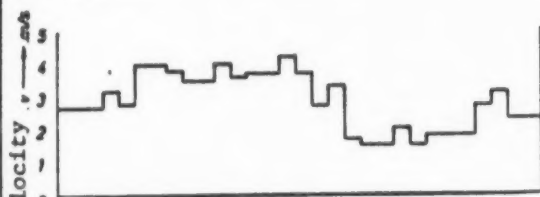


— Global wind speed  
 ---- Local wind speed

TÜV  
 Rheinland

Daily lines for the course of the global  
 and local wind speed.

Immissions,  
 city of Cologne  
 Measuring site: 13  
 Date: July, 1971

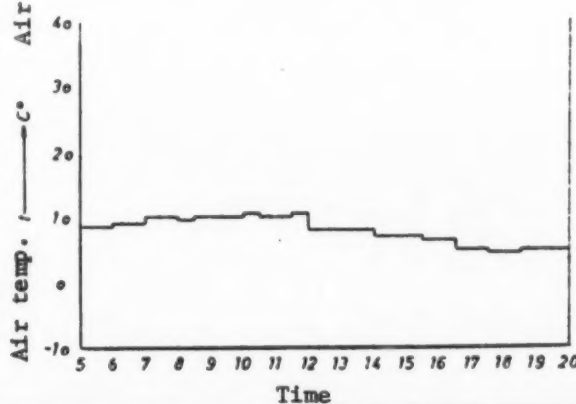
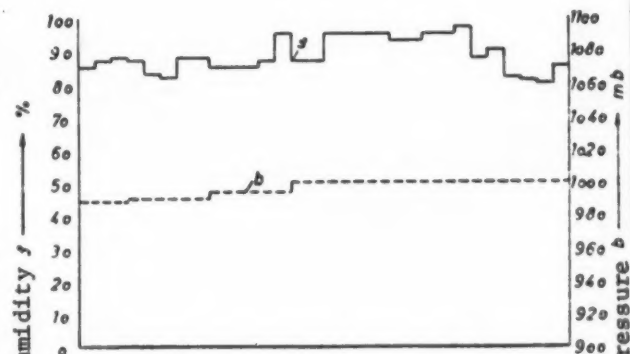


• Building alignment  
 • Street side  
 --- 0.75 m Height  
 — 1.5 m Height  
 - - - 4.5 m Height



Wind frequency

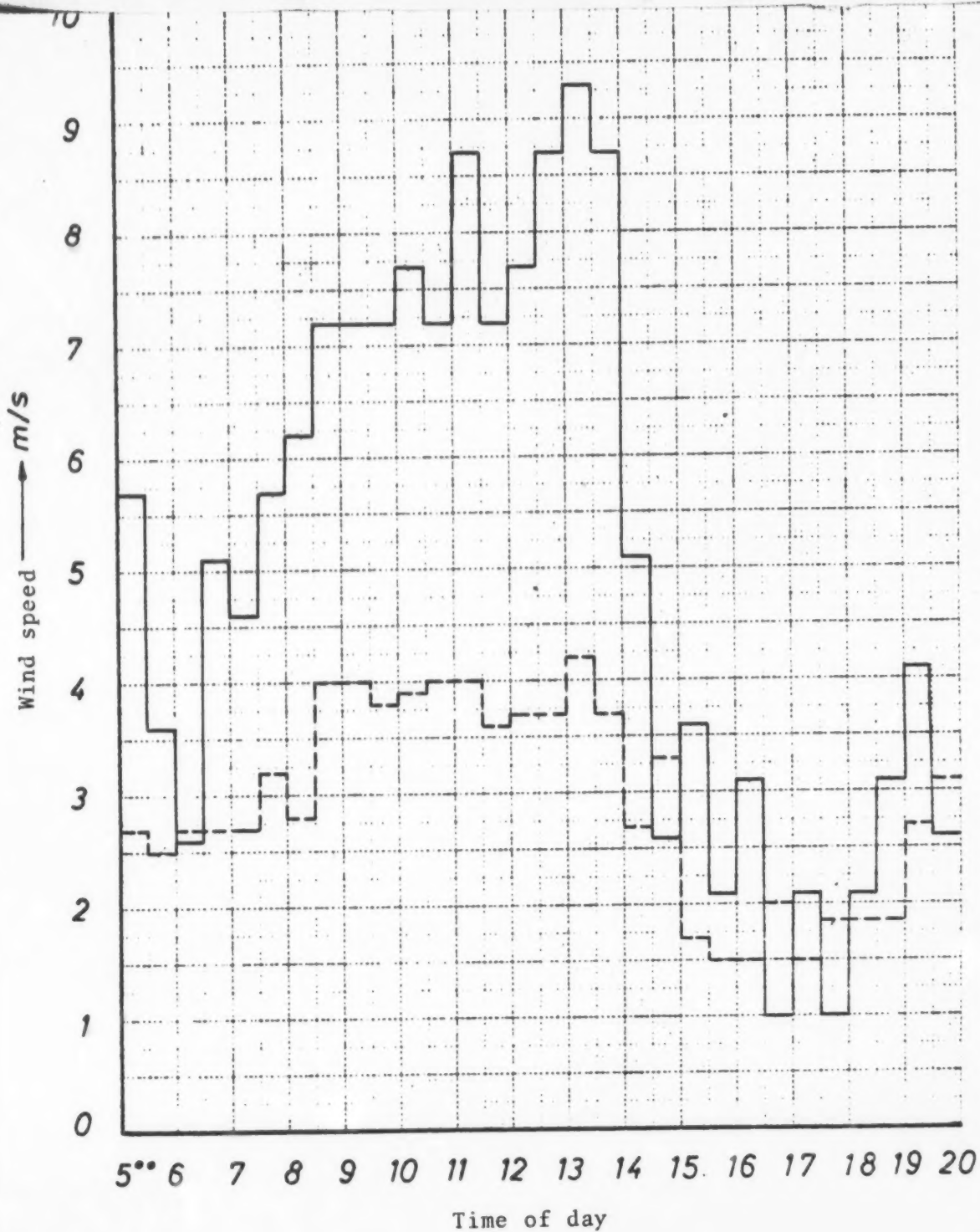
Wind direction relative to street axis



TÜV  
 Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
 city of Cologne  
 Measuring site: 14  
 Date: Nov. 18, 1971



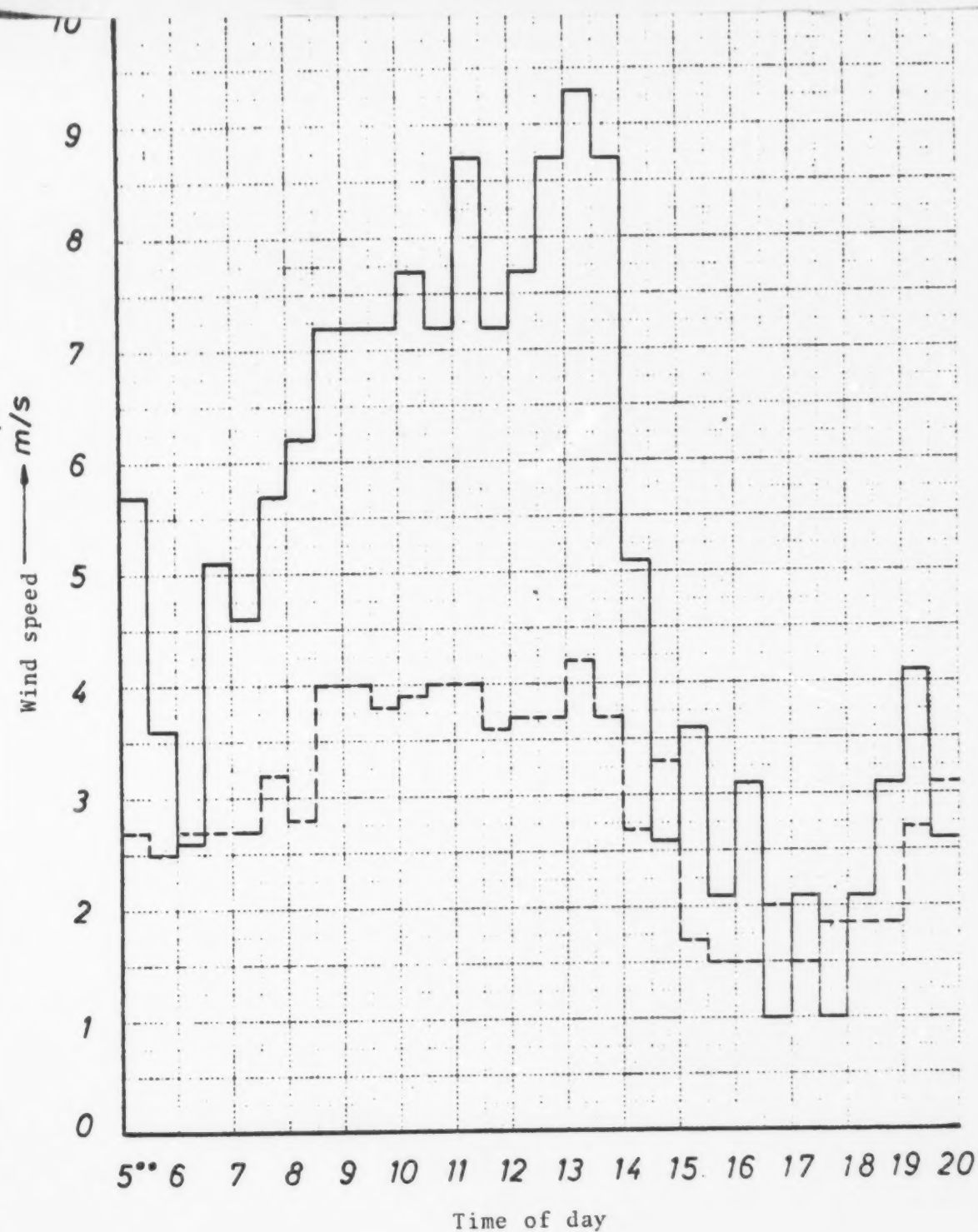
— Global wind speed.

---- Local wind speed

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Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 14  
Date: Nov. 18, 1971



— Global wind speed.

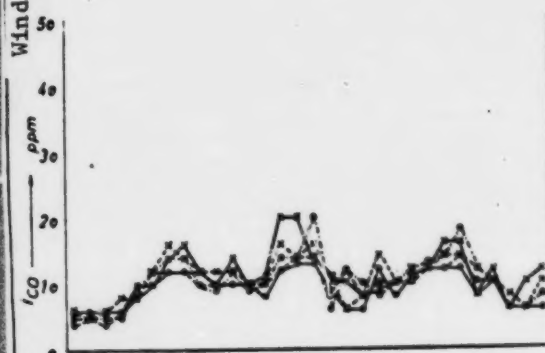
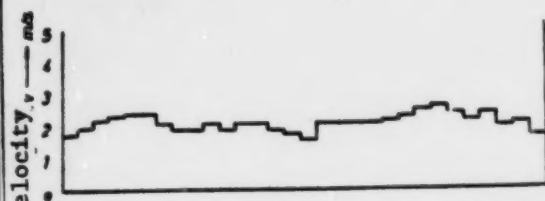
--- Local wind speed

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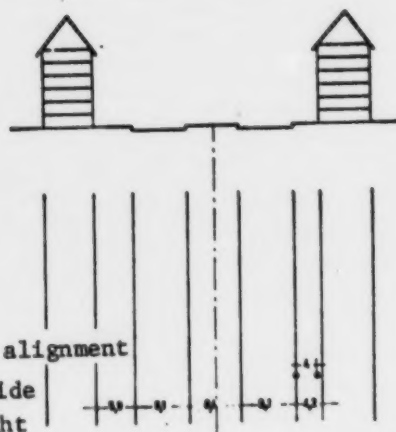
Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 14  
Date: Nov. 18, 1971

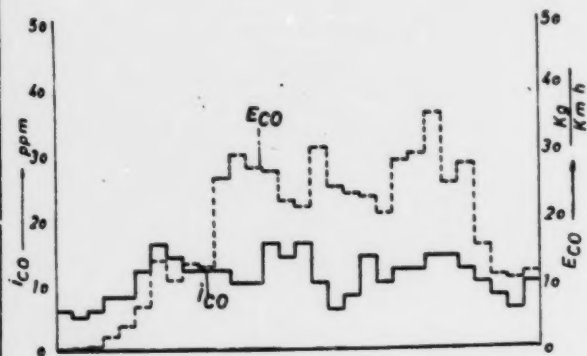




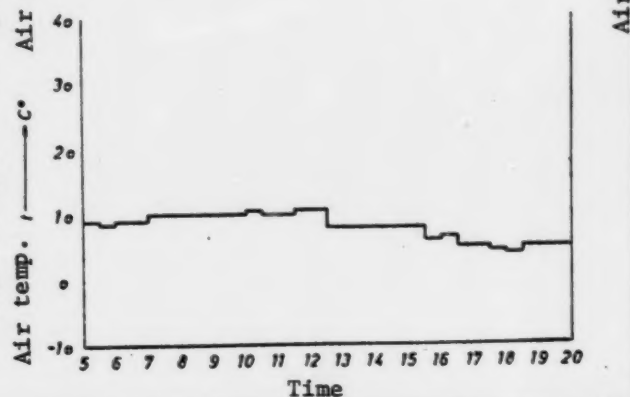
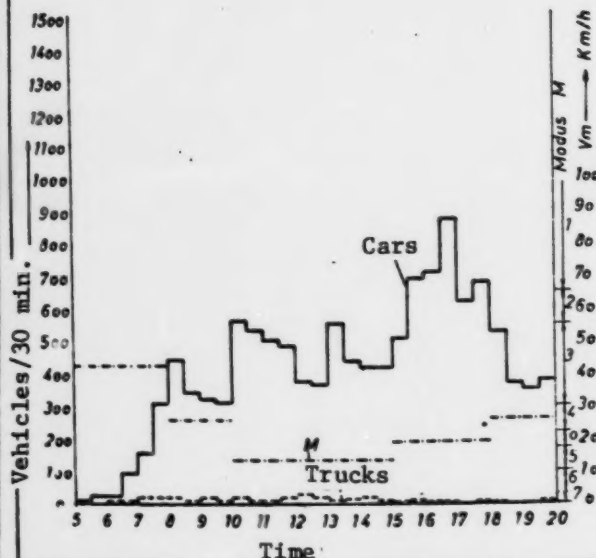
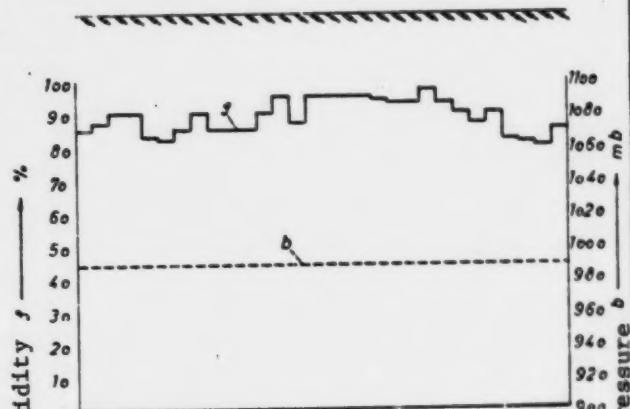
• Building alignment  
• Street side  
--- 2.75 m Height  
— 15 m Height  
--- 45 m Height



Wind frequency



Wind direction relative to street axis

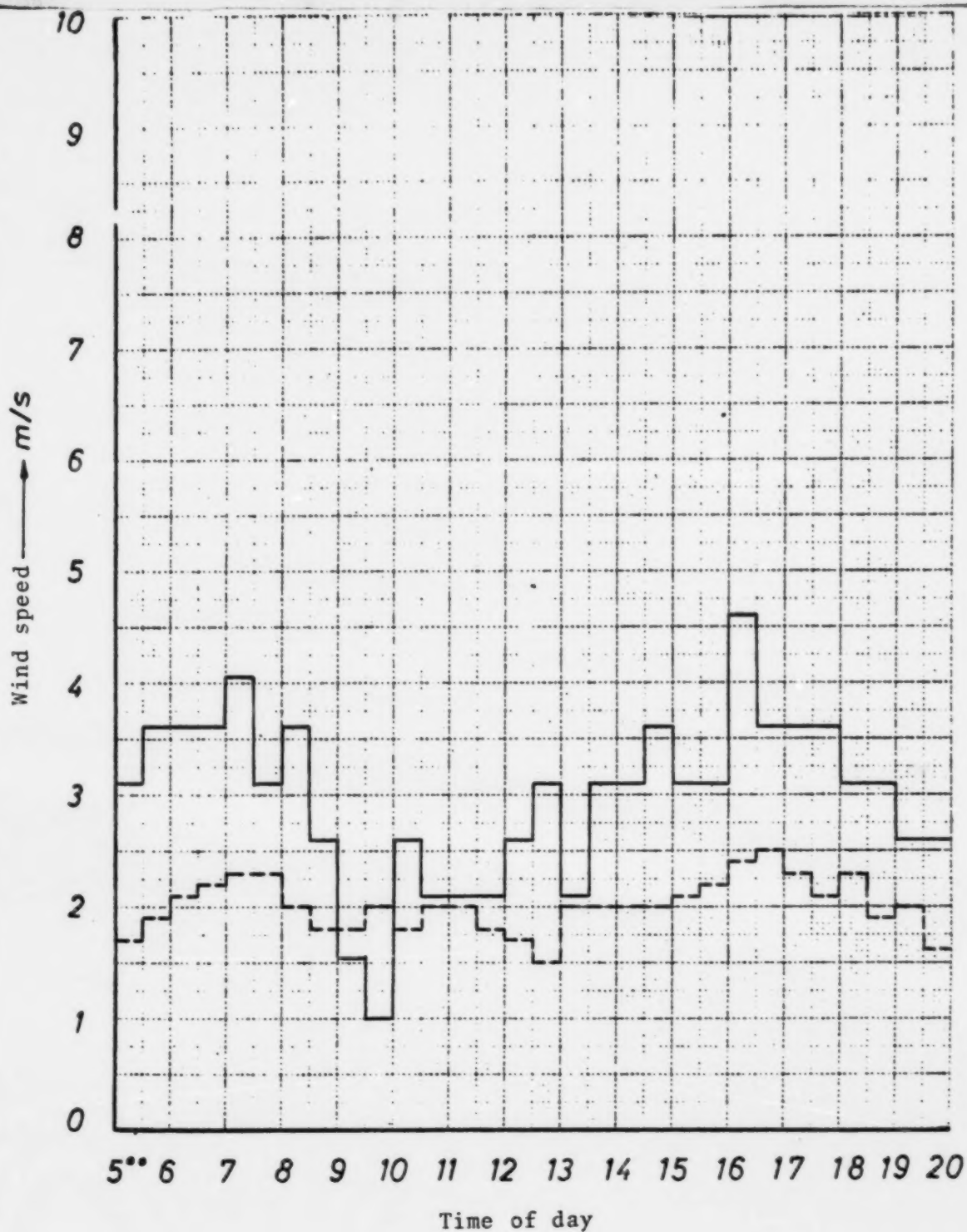


TÜV  
Rheinland

Daily lines for the course of the exhaust gas component CO (immission, emission), CO concentration at various heights, traffic density and meteorological quantities.

Immissions,  
city of Cologne  
Measuring site: 14  
Date: Nov. 19, 1971





TÜV  
Rheinland

Daily lines for the course of the global  
and local wind speed.

Immissions,  
city of Cologne  
Measuring site: 14  
Date: Nov. 19, 1971